‘Welcome to the Tiger Spotting Game!’

A psychophysical study of visual processing in Autism Spectrum Disorders

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Abstract

Atypical visual perceptual processing in Autism Spectrum Disorders (ASD) has been documented with reference to a number of tasks. Relative strengths and weaknesses have been uncovered, although the point at which strength becomes weakness is unclear. Using a psychophysical approach, the present study introduces a novel computer game, *The Tiger Spotting Game*, to assess a variety of visual processing tasks in 12 ASD and 12 typically developing age-matched controls. Tasks range from simple target detection to static size discrimination, dynamic change detection and dynamic size discrimination. The key finding is a marked deficit in dynamic discrimination in ASD children coupled with comparable static discrimination. This relative strength and weakness is discussed with reference to an executive dysfunction, specifically located at the level of visual attention.

Introduction

What are Autism Spectrum Disorders?

Autism and Autism Spectrum Disorders (ASD) are neurodevelopmental conditions represented as a triad of behavioural impairments (Wing and Gould, 1979). These impairments are broadly defined as: impaired social interaction, restricted repetitive and stereotyped behaviour, and communication deficits (DSM-IV). The Autism Spectrum serves to encompass a variety of different presentations of this triad of impairments. The spectrum represents a hugely diverse and heterogeneous clinical population: it spans from low-functioning autism, through to Aspergers Syndrome, high-functioning autism and Pervasive Developmental Disorders-Not Otherwise Specified (PDD-NOS). A great deal of attention has been given to the higher-level social dysfunctions apparent in ASD, at the relative expense of investigating low-level perceptual processing deficits. For example, while much study has been undertaken to localise deficits in understanding and visually recognising emotions (see for example Tantam et al, 1989), comparatively little has been done to investigate the most primary of possible underlying causes. Deficits in higher-level processing could have a plausible source at lower-level perceptual processing. Atypical perceptual processing then could underlie the social deficits and unusual behaviours often idiosyncratically associated with autism.

Sensory and perceptual processing is at the heart of everything we do as social beings. If we are to react to and interact with the world, it is our sensory modalities at the forefront. Consequent processing from these modalities allows us to begin the higher-level behavioural and cognitive processes needed to successfully interact with the world and those around us. This study investigates the sensory/perceptual deficits seemingly apparent in ASD.

Sensory (or low-level perceptual) abnormalities in autism.

Although observed in Kanner's original diagnosis in 1943 and more recently reported anecdotally and in empirical investigations, sensory (or low-level perceptual) impairment is not currently a diagnostic factor for ASD (DMS-IV). However, there is a growing body of evidence that sensory abnormalities and atypical perceptual functioning and experience may lie at the heart of the autistic condition. A number of qualitative and quantitative accounts of perceptual anomalies in ASD will now be reviewed.

Qualitative accounts

A small number of high functioning autistic individuals have been able to describe their experience of autism. Temple Grandin (1996), a high functioning autistic adult, has written a number of books describing her experiences. She not only details aspects of autism well described in theories, such as theory of mind deficits (Baron-Cohen, Leslie and Frith, 1985) and emotion blindness, but also describes her atypical behavioural reactions to some sensory stimulation. Similar vignettes have also been published by Williams (1996) and a number are reviewed in Stewart et al (2009).

Questionnaire studies have found experiences similar to those described in first hand vignettes in the majority of cases. Using the Sensory Experiences Questionnaire (SEQ: a caregiver questionnaire measuring the prevalence of abnormal behavioural responses to sensory stimulation), Baranek et al (2006) found that 69% of the autistic group had a mean SEQ score that exceeded 1 standard deviation (SD) of the mean for typically developing (TD) counterparts. Furthermore, 30% of the ASD group scored between 1-2 SD higher than neurotypicals and 39% had a score that lay 2SD from the neurotypical average. The vast majority of autistic individuals in the study were reported to experience a significantly greater number and variety of sensory experiences compared to typically developing individuals. While supporting Baranek's belief that sensory abnormalities may not be universal in autism (Baranek, 2002), the findings make clear that if this sample is assumed to be representative of the autistic population, the majority of ASD individuals will have some type of sensory and perceptual atypicalities. Having said that however, it is important to note that carer reports (like the SEQ) are open to misattribution of symptoms and the experience of the child will not clearly be understood without some sort of quantitative psychophysical or psychological data to suggest that sensory information is not being processed in a typical way. The study outlined in this dissertation provides this quantitative data and previous empirical work will also now be discussed.

Quantitative accounts

Quantitative psychological and psychophysical experiments have reported a number of findings of atypical sensory and perceptual functioning in ASD in all modalities, significantly deviating from that of both neurotypicals and other clinical groups (O'Riordan and Passetti, 2006; Porter and Coltheart, 2006). The most widely studied of these are those found in the visual modality, and these will be discussed in the next section and investigated further in the present study.

Visual processing in ASD

Before considering vision in ASD as a special case, it is important to outline and distinguish between the kinds of visual effects that are often found in vision research. Vision research can either find sensory effects or perceptual effects (or some interaction of the two). In the strictest sense, these two effects are not interchangeable, although often very low-level perceptual processes are referred to as sensory processes.

Visual sensation is a much more automatic (off-line) process than visual perception; in simple terms, it is light entering the eye which in turn creates an image on the receptors of the retina in the back of the eye (Goldstein, 2007). Sensation is physiological, while perception is a psychological process. Sensory effects, in the strictest sense, would therefore refer to problems with the modalities receiving stimuli. Until the more recent use of imaging technology however, most sensory processes could only be investigated in the context of a perceptual task, such as systematic techniques of measuring visual thresholds for detecting change, called 'psychophysics'. As they require a judgement to be made by a perceiver, these studies were therefore in fact often probing very low-level perceptual functioning.

Perceptual tasks involve the interpretation of sensory information from a modality and then acting upon that information to create a percept. For example, we see colours by interpreting what colour frequencies have entered the eye. Visual perception is gradiated, with different kinds of visual perception placing different demands on cognition and attention. Some perceptual processes do not involve conscious control, for example flicker sensitivity (Bertone et al, 2005) and the simple interpretation of physiological sensations, such as colour perception. These can be termed 'low-level perceptual processes'. Higher-level perceptual processing places increasing demands on cognition and attention, perhaps involving vigilance (requiring sustained attention) or comparing and contrasting of different stimuli or features. These tasks have a much higher cognitive load, requiring various types of attentional control, and conscious perceptual judgement. The more a perceptual task allows for planning and also the voluntary control of eye movements and visuospatial working memory (such as visual search or perceptual discrimination), the more it can be said to be an executive task. An example of such a task then would be feature discrimination.

There seems to be a pattern emerging that ASD individuals are often superior or comparable to neurotypicals in low-level perceptual tests, while they are outperformed on more demanding higher-level perceptual tasks. Examples of these relative strengths and weaknesses in visual processing will now be discussed.

Enhanced visual abilities in ASD

Often in autism literature, investigators report findings of deficits in ASD participants on a variety of tasks. However, the study of visual search and other low-level perceptual tasks has serendipitously found a number of tasks in which ASD participants outperform control groups. These seemingly superior abilities will now detailed, followed by the major theoretical explanation forwarded, as well as alternatives to or revisions of this theory.

Enhanced local processing

Embedded Figures Task (EFT)

The Embedded Figures Task (EFT: Gottschaldt, 1926) is one such task in which ASD individuals often excel, relative to TD participants. In this paradigm, target objects are hidden within a larger picture or scene and subjects must determine whether the target is present or absent, as quickly as possible. It is a local visual search task, in which parts of the scene must be processed individually in order to perform well. A number of studies have found ASD participants to significantly outperform TD participants in the EFT, being both quicker and more accurate (Shah and Frith, 1983; Jolliffe and Baron-Cohen, 1997). Although not all investigators have found a significant difference between ASD and TD subjects on the task, these nonsignificant findings are still theoretically important, as even being as good as TD subjects highlights the lack of any deficit in local processing (Brian and Bryson, 1996; Ring et al, 1999; Ropar and Mitchell, 2001). ASD subjects' superior ability in this task has predominantly been explained as an example of Weak Central Coherence (WCC: Shah and Frith, 1983). This theory will be discussed in full at a later point.
Local processing in ASD has also been assessed in the Navon Letters Task (Navon, 1977) and findings from these studies will now be discussed.

Navon Letters Task

Enhanced local processing (at the expense of global processing), as seen in EFT, is also apparent in the Navon letters paradigm (ibid): when viewing a large letter (the global stimulus) composed of multiple examples of a different smaller letter (the local stimuli), ASD participants tend to identify the smaller (local) letters, rather than the larger one (Wang et al, 2007). However, task variations by individual investigators have led to some findings that appear contradictory to this general trend. One variation of the Navon letters task (Ozonoff et al, 1994), resulted in a global interference effect in ASD: slower target detection times were recorded when the target was local and the global letter differed from the local (target) letter, for example, a large 'S' comprised of small 'R's. This was the same pattern as was found in TD participants and a group with Tourette's syndrome. Conversely, Mottron and Bellville (1993) found that their (autistic) case study subject showed local interference, meaning that when the local and global letter did not match, the subject was slower to identify the global letter. This finding is in line both with the WCC theory and the general trend within the literature. There was a key difference between these two latter tasks: in Ozonoff et al's study, subjects were explicitly instructed to attend to *either* the local or global target and report that letter. Mottron and Belleville on the other hand required their subject to report *both* local and global targets in each trial. The former therefore is a selective attention task, while the latter is a divided attention task. When Plaisted et al (1999) administered both versions of the test to a single (control and clinical) group, they found that the discrepancy between the two tasks, and therefore the two kinds of attentional demands, remained. As this was apparent when the same children had completed both tasks it is clear that in a divided attention task (in which no one kind of attention is explicitly required), ASD children will preferentially use local processing, as has often been found in EFT. As their performance mirrors that of TD children in selective attention tasks, especially when global attention is primed, it appears that ASD's superior performance in tasks involving local search is due not to a deficit in global processing, but an enhanced local processing. This is a very important point for the WCC theory, as will be explained later. It may be that ASD individuals prefer to process visual stimuli locally, perhaps as it reduces the amount of information to be handled at any one time. If this is the case, then it can be speculated that attending to multiple stimuli simultaneously may be causing sensory overload and may be causing some distress. This would explain some of the unusual behaviours exhibited in ASD, such as tending to use peripheral vision (Hirstein et al, 2001), and in the case of audition, covering ones ears in crowded situations (Minshew and Hobson, 2008).

Learning patterns

Plaisted et al (2003) employed a pattern-learning task to assess featural and configural processing in ASD and TD children (essentially the local and global processing assessed in the EFT and Navon Letters task). Subjects were instructed to learn, through trial and error, which of two button-press responses three different stimuli corresponded to. When presented individually, stimulus A and B (different coloured dots) corresponded to the left button: when presented together (so, AB), the correct response was to press the right button. This means that if featural processing were used in the case of AB being presented, the incorrect response would be given (as both components separately require the left button to be pressed, but together the correct response is to press the right button). It was found that ASD children were significantly worse on trials in which stimulus AB was presented compared to when stimuli A and B were shown separately. The converse was true for TD subjects, that is, global processing was better in TD individuals while the ASD group found it easier to process the stimuli locally. There was a trend toward a significant group difference for feature trials (A or B) suggesting that the ASD children were close to outperforming TD on featural (local) processing in this task.

Explaining enhanced local processing

EFT, the Navon Letters task and Plaisted et al (2003)'s pattern learning tasks are often most readily explained by Weak Central Coherence (WCC) theory (Frith, 1989). This theory will now be outlined in full and with reference to these areas of enhanced performance by ASD subjects.

Weak Central Coherence (WCC)

The WCC account (Frith, 1989) assumes that typical perception comes about from the integrative perception of an object or scene's component parts. Typical perception is therefore described as involving global processing. If a scene is processed globally, the whole scene will be processed, with all components being processed together (integrated) to make a coherent whole: information is processed with a "drive for meaning" (Bartlett, 1932). Conversely, if a scene is processed locally, then different aspects of the scene will be processed but they will not be considered relative to other components in order to create a story that binds them together to create the scene.

In EFT, ASD superiority is therefore attributed by WCC to their use of local processing (and deficient process of integrating several pieces of information), while their typically developing counterparts tend to use global processing. Typically developing children's use of global processing means that the gestalt of the scene prevents the 'pop-out' of the targets as experienced by ASD subjects. By utilising a more piecemeal search (local processing) of the scene, the targets 'pop-out' as the ASD subjects are free of the semantics and gestalt of the scene.

An alternative to the WCC account of this pop-out effect, forwarded by Plaisted (2000), places emphasis on an ability to ignore irrelevant information, rather than processing the scene locally.

Similarly, the finding of preferential use of local processing in the Navon Letters task suggests that ASD's visual processing is geared towards a local processing approach, although as evidenced by Ozonoff et al (1994), there is no global deficit, merely a local processing bias apparent in ASD. Findings such as this brought about a revision of the WCC account, which moved from believing ASD was a deficit in global processing, to advocating the idea that local processing is merely the prevalent cognitive style in ASD.

The finding of local interference in ASD in situations where global processing is not primed suggests that in spontaneous (unprimed) visual processing, the process of integrating several pieces of information is deficient in ASD. Plaisted (2000) however questions this assumption, as the extent to which the Navon Letters task assesses integrative ability seems small. It is suggested then that a conjunctive search task would be the most appropriate and clear method for investigating unimodal integration abilities. Several studies have been conducted using conjunctive searches and these will now be described alongside other studies of enhanced discrimination abilities.

Enhanced Target Discrimination Abilities

Some discrimination abilities have also been found to be superior in ASD individuals, for example, in certain tasks requiring the discrimination of targets from flanker items in a random array (as opposed to hidden within a scene, like the EFT, or arranged to create a meaningful global pattern, as with the Navon letters task). Conjunctive search tasks have allowed for the investigation of the factor that determines the difficulty of a discrimination task (or detection of target among distracters), both for TD and ASD individuals.

O'Riordan and Plaisted (2001) used two types of conjunctive search tasks to identify the cause of the apparent enhanced ability among ASD individuals in visual search and other low-level visual-perceptual tasks. Conjunctive search tasks involve stimuli with multiple features that must be integrated in order to correctly differentiate target from distracter. ASD and TD children performed three conjunctive search tasks, each varying in the number of stimulus features and the ratio of shared:unique features for the stimuli and distracters. It was found that the important factor in visual search was not the number of features to be considered and integrated, but the degree to which target and distracters were similar, with ASD participants able to discriminate more difficult targets and distracters (i.e. those with a greater proportion of shared than distinct features) at a faster rate than neurotypicals. This study seems to support findings of superior visual search and 'discrimination' in ASD, although it is important to note that these are quite limited paradigms, and discrimination of target relative to flanker is certainly not the same as discriminating between two targets (that is, a psychophysical discrimination between two targets on the basis of e.g. size or brightness). Indeed, very little research has been conducted in the last 40 years on discrimination of highly similar targets in children, as a pure discrimination task, not packaged as part of a visual search task. This is one of the areas to be addressed in the current study. These findings also provide further evidence to reject the initial assumption of WCC that local processing bias in ASD is a result of deficient integration of parts into a gestalt: the number of features to be integrated did not hamper ASD task performance. This rejection of the WCC assumption of an integration deficit suggests that Plaisted's (2000) description of EFT superiority in ASD as arising from the ignoring of irrelevant local stimuli may be a more appropriate means by which to understand the superior performance in conjunctive search tasks and the EFT and Navon letters task: it appears to perhaps to lie more in the domain of executive function than of perceptual functioning.

What causes this enhanced 'discrimination' ability in conjunctive search?

The authors of the above study suggest that the likely reason for this ability is a reduced perception of sameness in ASD individuals, with the perception of differences between items appearing augmented.

Eye tracking studies have suggested that different patterns of eye movements may also be playing a role in this enhanced discrimination ability. Kemner et al (2008) questioned whether enhanced visual search in PDD adults was due to enhanced 'discrimination' ability, as suggested by O'Riordan and Plaisted (2001), or whether it was instead due to a more efficient search method. Using a target-among-distracters paradigm involving vertical and slanted lines, the authors found that the PDD group was significantly quicker to detect the target than TD subjects. The PDD group also exhibited a different pattern of visual fixations and an unusual trait with respect to their saccadic eye movements. The duration of fixations was the same for both clinical and control groups, although the number of these fixations was less in the PDD group. This finding of fewer fixations was coupled with an absence of saccadic eye movements for a number of individuals in the PDD group. This suggests that often a glance was all that was needed for the target to be picked out from the distracters. The authors conclude that this is indicative not of a different or more effective search strategy, but that the perception of differences may be augmented to the extent that a glance is all that was needed for PDD participants. This supports O'Riordan and Plaisted's (2001) suggestion of enhanced discrimination (in target-distracter search tasks) due to diminished perception of target-distracter similarity. It could also be that these findings are able to be explained, as Plaisted (2000) suggested, by an ability of ASD subjects to ignore irrelevant stimuli, such as those features that are common to both target and distracter. This could be possible as features are typically each processed individually before a whole object is perceived (Teisman and Gelade, 1980; Wolfe et al, 1989).

Kemner et al's finding of a lack of saccadic eye movements and apparent detection in a glance is an interesting one, but suggests that this enhanced ability relative to TD individuals may only be evidenced when stimuli are close enough together to allow this single glance. If targets are located more disparately, it might be the case that this superior ability is lost, although ASD subjects are likely to still perform as well as controls, as the augmented perception of differences between stimuli suggested by O'Riordan and Plaisted would still be evident.

Deficient visual perceptual processing in ASD

As we can see, there seems to be a certain class of visual tasks in which ASD participants perform very well. At the same time, there are a number of visual tasks in which ASD participants significantly underperform compared to neurotypical controls. These will now be discussed with reference to the theories previously outlined.

Perceptual learning

Plaisted et al (1998) assessed perceptual learning in adults with high functioning autism and age-matched neurotypicals. Participants were required to learn the correct response (two choices) to a variety of variations of a pattern of circles. In every variation of the pattern, three of the seven circles maintained the same spatial relations throughout, whilst the remaining four were moved very slightly. Some of the examples of the pattern were used in a pre-exposure phase and were then used alongside the remaining examples of the patterns in a test phase. These stimuli were therefore familiar and novel respectively in the test phase. It was hypothesised that the autistic participants would show an enhanced perceptual learning effect relative to TD subjects. This was expected due to autistic subjects tending to process unique features very well and common factors comparatively very poorly (O'Riordan and Plaisted, 2001; Kemner et al, 2008).

Contrary to their hypothesis however, ASD adults were found not to show any perceptual learning effect, treating novel and familiar stimuli the same. They were however significantly better than TD participants at discriminating between the highly similar stimuli when they were novel.

Explaining the lack of visual perceptual learning

Three theories are considered by Plaisted et al (1998) to explain the absence of perceptual learning of patterns in ASD adults. The WCC account, detailed previously with reference to the EFT and the Navon Letters task, is discounted in this case. As we know, in the case of EFT and Navon Letters, TD subjects tend to process stimuli globally, whilst ASD subjects process at the local level. If TD subjects were processing exclusively at the global level, that is, processing the pattern as a whole, this would eradicate common features between stimuli (the three unchanged circles) and every stimulus would be unique, therefore there is no way in which perceptual learning can take place: learning can only take place when there is the opportunity for generalisation and rule formation. As there was a clear learning effect in the TD participants it is clear that they were not using purely global processing. This assumption of WCC therefore is not true in this case. The assumption that ASD would use local processing also fails to explain their performance on this task, as using a local strategy does not theoretically appear to have any disadvantage compared to using a global strategy.

Attentional problems are also cited as a possible explanation for the pattern of performance in the study. It is suggested by the authors that in phases prior to the test phase, it may be the case that subjects only attended to a small section of the stimulus (so the spatial relations of a sub-set of the circles in the stimuli). In the test phase it might be the case that the sub-section attended to previously is in fact the sub-set of the stimuli that remains the same (as 3/7 circles remained unchanged between variations of the stimuli). As ASD individuals have been found to exhibit executive functioning problems with respect to attention shifting (discussed below with reference to ODR), in this situation they would be unable to shift their attention to a different part of the stimulus that would enable them to accurately make the discrimination. With no such problems with shifting attention, TD subjects would be able to move their focus of attention to a different part of the stimulus in order to successfully make the discrimination.

The authors also suggested that the lack of any learning effect in the ASD participants might have been due to an inability of generalisation: perhaps ASD subjects did not recognise that in every case, 3/7 of the stimulus was unchanged. In other words, the ASD participants were unable to extract and integrate similarities across a temporal gap. Without the ability to generalise across perceptual experiences there is no scope for perceptual learning as connections are not made between stimuli. Both this theory and the attentional theory could explain this finding. The question is then, is the finding due to a possible executive failure due to the demanding online nature of the task, or is it perhaps just due to where participants are looking?

Oculomotor Delayed Response task

The Oculomotor Delayed Response task (ODR: Minshew et al, 1999) has highlighted marked deficits in ASD subjects' ability to switch attention from one location to another. The ODR task is similar to the Posner cueing paradigm (Posner, 1980). Participants must respond as quickly as possible to a laterally located stimulus, after being cued either to the side on which the stimulus will appear or the opposite side. The task is designed to assess how good participants are at disengaging, shifting and re-engaging attention and probes both covert and overt attention, depending on the type of cue used. Endogenous cues, such as an arrow replacing the central fixation point, tap into endogenous attention, which is attention we can purposefully control, i.e., subjects are able to choose not to overtly look in the direction the arrow points. Exogenous cues are cues shown at one of the two possible locations and the cue is most commonly an illuminated box. These types of cues automatically capture attention. Typically, TD subjects are slower to respond to targets following an invalid cue (that it, a cue either pointing to the side the stimulus will *not* appear on, or a cue presented at the location where the stimulus will *not* appear).

ASD participants have been found to be impaired on the ODR task, relative to TD subjects (Minshew et al, 1999). They are slower, once invalidly cued, to move their attention to the correct location, and are more inaccurate in remembering the location, compared to TD subjects. In a similar task, the Anti-Saccade task (AT), they often show more response suppression errors, that is, they appear unable to choose not to allow their attention to follow a cue and inhibit the response.

Explaining poor performance on the ODR task

Deficits in the ODR and AT task appear to originate from an executive dysfunction, specifically in attention and/or visuospatial working memory. While anomalies of executive function were cited by Plaisted (2000) to be responsible for superior target detection in EFT and target-among-distracter tasks, it appears that executive functioning atypicalities do not consistently result in superior performance by ASD subjects. For example, in tasks specifically requiring that attention be distributed among stimuli and when task relevant information has to be held in visuospatial working memory.

Identifying a common locus of deficient higher-level perceptual processing

Both perceptual generalisation in pattern recognition and attentional requirements of the ODR and AT tasks appear to be deficient in ASD, relative to TD counterparts. Although there are a number of different possible theories, executive dysfunction, specifically related to attentional control (Plaisted et al, 1998) and visuospatial working memory (Minshew et al, 1999), has been highlighted as a possibility in both instances. This may also explain the paradox of superior performance in lower-level perceptual tasks without these demands. It may be that varying demands on executive functioning can unify the strengths and weaknesses evidenced in ASD individuals' performance on visual perceptual tasks.

A plethora of studies with little scope for meaningful comparison

As can be seen from the literature already cited, there appear to be both strengths and weaknesses of visual processing in ASD, although there is also disagreement among researchers. Not every strength or weakness is reliably replicable and this is likely due to the vastly different methodologies used by different investigators.

Firstly, different subject groups are used, both for clinical groups (mixed diagnoses or specific diagnoses) and control groups (age-matched or IQ-matched). The effect of using different clinical groups can be seen in EFT research: Brian and Bryson (1996) found no enhanced performance in a group of high-functioning autistic and PDD participants, while Jolliffe and Baron-Cohen (1997) did find significantly enhanced performance in their clinical group comprising autistic and Asperger syndrome adults. Secondly, disparate stimuli being used in each investigation could also in part explain discrepancies in resultant group effects. The presentation properties of these stimuli also vary across studies, with some stimuli being shown for very brief periods, and other studies showing stimuli for markedly longer periods of time. Finally, it is also possible that differing task instructions could be contributing to contradictions within the literature, with some instructions being much more explicit then others, some using verbal instructions, others written instruction. The basic language used in instructions can easily change the outcome of the study, as instruction-action congruity has been found to have a direct relationship with motor response times (Borghi and Scorolli, 2009). Instructions asking the participant to perform an action on the stimuli that is congruent with the ideas and semantics of the task will produce a faster reaction time compared to when the instructions are more abstract and not congruent with the action being performed in response to the stimuli.

All of these intricacies of experimental design are differentiating experiments and their findings and making it increasingly difficult to compare and contrast. This hampers our ability to piece together a picture of visual processing as a whole, not just independent strengths and weaknesses in certain paradigms.

As well as problems with discrepancies between studies of the same task (i.e. visual search), due to differences in methodological parameters, the vast difference between lower- and higher-level perceptual tasks with respect to these parameters means that it is very difficult to understand where superior performance ends and marked difficulties begin.

As yet, there seems to have been no investigation into visual processing in ASD that has tried to address these problems. By delivering a variety of graded tasks, ranging from basic detection to more complex cognitive decision-based visual tasks, it should be possible to establish which areas are relatively problematic for ASD children. By using the same stimuli, similar instructions throughout and packaging all tasks into a coherent computer game format, it should be possible to carefully compare tasks in a way that is not possible from previous studies where task variables are altered by each investigator.

Using a psychophysical methodology, the present study introduces such a game, assessing focal and peripheral target detection, static size discrimination, dynamic change detection and dynamic size (or 'simulated speed') discrimination in a group of ASD and TD children.

The psychophysical method

Psychophysics is an experimental method that has recently received very little attention. Pioneered by Wundt, Fechner and Weber in the 1800s (1862; 1860; 1834), psychophysics is a method by which original investigators searched for laws that could describe our experience of the world in terms of the properties of the stimuli within it (Shapiro, 1994). It was concerned with obtaining values which could be used to calculate the increase or decrease of a stimulus parameter necessary to elicit a response to suggest that two stimuli were recognised as being different (Weber's Just Noticeable Difference: JND (Weber, 1834)). Psychophysics has also been considered in behavioural terms (Barlow, 1982), with it being described as the "study of how the subject's report varies with the physical parameters of the stimulus" (Shapiro, 1994, p47).

Regardless of whether the emphasis is on the sensory level or the behavioural level, Hyslop's definition of psychophysics seems appropriate in both cases: it "confines its investigations to phenomena which intermediate between purely mechanical events and purely reflective consciousness" (Hyslop, 1886, p259). Psychophysics then is our response to stimuli in terms of quantifiable responses such as RT. Size discrimination is an example of the kind of task that can be used in a psychophysical investigation, although little work has been conducted on it in recent years. The present study will use size discrimination, within a psychophysical design, as its focus.

Present study

Using the psychophysical method outlined above, the present study uses a novel computer game format in order to further illuminate the question of unimodal integration and the development of relational visual perception in ASD and TD children. It will also include suitable baseline conditions in order to provide a full account of participants' relative strengths and weaknesses in a controlled experimental design.

The game will present five tasks of tiered difficulty, reflecting the gradation of perceptual processing. Players must detect stimuli and perform size discrimination tasks. The discrimination of static stimuli will be compared with the discrimination of moving (optically expanding) stimuli. Optical expansion, or 'looming' motion does not appear to have been well researched in children, although it is very appropriate here: it is essentially a size discrimination task, with the added feature of requiring ongoing attentional monitoring. Optical expansion in this case is a number of images, each getting bigger with each consecutive frame, being transposed on top of one another at the centre point. With the images constantly changing size, the discrimination will only be successful after careful and constant monitoring of the two stimuli, unlike in static discrimination where it may be quite sufficient to attend to each stimulus once then make a decision.

Questions and hypotheses

Static detection

Due to enhanced target-nontarget discrimination abilities, performance on detection tasks may follow a similar pattern. However, as target-detection (as a purely visuomotor task as opposed to a visual search task) has not been widely studied, it is not possible to make a firm prediction of the performance of ASD children in a detection task in which visual search is not necessary. As clumsiness and slowness are often reported in descriptions of autistic children, (Asperger, 1944; Klin, 2006) it seems possible that visuomotor skills may be impaired, resulting in slower detection times. If ASD children are slower to make a simple motor response, this suggests that findings of superior visual processing skills are superior over and above potential motor slowness.

Target location may produce group effects in static detection tasks due to the common use of peripheral vision in ASD (Bogdashina, 2003), although as previous findings suggest that there may not actually be any benefit in using peripheral vision (Hermelin and O'Conner, 1970), this may not be the case. Again, this area has not been extensively researched.

Static discrimination

It is hypothesised that the clinical group will perform at least equally as well as the control group in the static discrimination task, in line with enhanced or equivalent target-nontarget discrimination abilities in ASD and superior ability in target discrimination where stimuli differ from distracters on relatively few features.

Static discrimination is an important baseline for dynamic discrimination, as it gives an indication of basic relational perceptual skills without the extra demands on attention present in the dynamic discrimination task.

Single dynamic change detection

As the task requires focused attention and makes no demands on attentional switching it is hypothesised that the ASD group will perform at least comparably to the TD group. This task will provide an important baseline for dynamic detection. The results will give an indication of each group's ability to perceive looming and changes in acceleration, without the confound of discrimination and attention switching.

Dynamic discrimination

It is hypothesised that ASD subjects will show much slower reaction times than TD subjects for dynamic discrimination. It is hypothesised that they will ineffectively distribute their visual attention, thereby increasing the amount of time needed until a difference between the stimuli is detected. This finding would be explained with reference to executive dysfunction.

Hypothesis summary

- ASD and TD may be comparable on static detection, or may be slower due to visuomotor delay.
- ASD and TD will be comparable on static discrimination and single dynamic change detection.
- ASD will underperform TD on dynamic discrimination.

Methods

The designing and programming of the computer game was a significant part of the methodology and represented a large investment in the time allocated to the project. For this reason an argument for game-based procedures and a detailed account of the methodological and practical problems encountered in this case will precede a standard methods section.

The argument for game-based experiments and the game-making process

While previous psychophysical tests have been informative, there seems to have often been a lack of creativity in their design. This is not to say that they are not methodologically sound, but they are often designed explicitly as an experiment, with little attention paid to subject enjoyment and engagement in the task. To work with children, it has to be fun: if it is not fun the child will lose interest. Playing on a child's natural competitiveness seems to be a good way to engage participants, particularly autistic children. As probably the majority of children are now very familiar with video games, creating a computer-based game seems like the best way forward if we are to successfully return to engaging and informative psychophysical experiments. This is especially true for autistic children, as a computer-based game requires no social interaction with the experimenter apart from listening to initial instructions, all of which can be reinforced in-game by the game's narrator or some other in-game character. With so much technology available to psychologists, it seems appropriate to utilise this technology to its full potential in order to create engaging paradigms for children, whilst retaining the accuracy necessary in psychophysical research.

While a large number of investigations do use computerised experiments, there is little literature available on the process of producing these experiments and games. It would be beneficial for researchers to speak formally about technology available to them, appraising its potential, but more importantly for other researchers, discussing its limitations. There is evidence of clear limitations on internet forums and from informal discussions with other researchers, yet none of this is reported formally. With a seemingly high chance of novice game-programmers encountering some of these potential problems, it is important that the design and technical requirements of the game be carefully considered at the outset.

Creating a computer game

The first task is to assess the practicalities of your ideas, given the software, time and skills at your disposal. As psychophysical studies are concerned with reaction times, it is vital that there is a practical way to accurately record responses. It is also important to select a computer programme that is able to handle the different kinds of stimuli you wish to include in your study. Finally, it is vital that the method you choose makes use of skills you already have, or skills that are easily learnt, so that interdisciplinary research does not become the only way by which the investigation is possible.

There are a number of computer programmes designed and marketed specifically for psychological and psychophysical research, each of varying complexity and allowing for the design of more or less complex game-like environments.

E-Prime (PST) seems to be the most widely available programme to psychology students. E-Prime allows researchers to design, create and administer computer-based experiments, all within a single programme, requiring little knowledge of computer programming languages for simple experiments. The version used in the current experiment (E-Prime Professional 2.8.2) claims to be able to handle multiple stimuli simultaneously, presenting video, audio and images. It can work in conjunction with a serial response box (SR-box), which allows for extremely accurate *RT*s to be recorded in psychophysical experiments.

Other programmes include Superlab (Cedrus) and Psyscope (Cohen et al, 1993), although neither of these is able to offer the range of features available in E-Prime. Having said this however, there were a number of problems with E-Prime during the programming and design of the present study, which prompted a search for a more suitable programme to be used in any revisions of the game created for the present study.

Problems encountered while programming the game

The most common problems arose due to problems with E-Prime itself. These will now be detailed.

Memory capacity when using video files

Memory issues were a frequent problem throughout the design process. Using large numbers of video files, which were relatively large in terms of space on the computer's memory resulted in a number of errors citing problems with buffering the videos and "too many retries". The latter error was somewhat of an unknown quantity. A search on the PTS user forum suggested that the cause of this was not known. It was suggested that it was a bug in the programming of E-Prime. The use of videos had to be scaled down, resulting in fewer trials and less variety of stimuli as had originally been intended. By the time the extent of the problem inherent with E-Prime was realised, it was too late to realistically learn a new programme.

Once this limitation was discovered, the design was altered slightly to allow for this unexpected problem. However, a number of other problems, unrelated to the stimuli or the design of the game further delayed progress.

Unidentifiable bugs in the software

Within E-Prime, the game used inline objects and label objects. Inline objects allow you to enter lines of script, for example:

```
"if accuracy=1 then goto label2"
```

Scripting is a way of instructing a computer programme to carry out a certain function that is not achievable using the pre-made commands within E-Prime (a number of simple experiments can be created in E-Prime using only the pre-made 'objects' in the programme).

An untraceable problem in E-Prime resulted in the programme sporadically misaligning label names. When the script was checked it was found that the label names no longer matched, so the experiment would not run. As it is not possible to edit the script generated by the 'compile' function, (which shows the entire game as a script of computer language) it was not possible to correct this problem. The experiment had to be re-written from the point before labels were added. This had to be done a number of times.

The final major problem encountered with E-Prime itself was unexplained crashes. A large amount of time was spent restarting the software after it unexpectedly quit without warning and without saving work carried out since the last time the game was saved. At one point the programme crashed reliably after adding, modifying, deleting or clicking on three e-objects (objects dragged onto an experiment timeline). As soon as the mouse was clicked a fourth time the programme would crash and quit without saving. Once this pattern was recognised it was clear that work had to be saved after every click of the mouse.

Computer problems

There was also a problem with the computer itself, which exacerbated the initial memory problems found in E-Prime.

A problem with the .NET on the computer was encountered and this delayed work significantly. The problem was preventing E-Prime from playing videos (even when the number of videos was smaller than what was later discovered to be the limit) and consequently the experiment was unable to be tested and piloted for some time. Moving to another computer to work on E-Prime was not an option due to insufficient memory on open access computers and indeed the other computers in the lab. Memory on the desktop computer used to create the game had been increased to 4GB in order to facilitate the use of the video files. Cutting the E-Prime file in two and checking those on another computer was not possible as there was perceived to be a real chance that once the two halves were checked, modified and reunited in one file, a new error would be introduced and the time spent modifying the two halves would have been wasted time. Errors such as this were frequent before this point so it was deemed more useful to concentrate all efforts on solving the computer problem than to split time between the .NET problem and continuing with E-Prime.

Despite the problems outlined above, a computer game (both a pilot and proper version) was successfully programmed and will now be detailed fully.

Pilot study

It was decided that a psychophysical pilot study should be conducted in order to identify the optimal parameter values for the videos to be used in the experiment proper. Unfortunately it was not possible to use all of the possible permutations of the key variables in the experiment due to restrictions in E-Prime's capability to handle multiple videos files, as detailed above. It was decided that videos included in the pilot for which there were accuracy rates of 80% or higher would be included in the experiment proper, on the condition that there was a significant difference between some of the videos (so there would be easy and hard videos). As it was anticipated that ASD children would perform less well than TD children, having videos that were too difficult for TD subjects would likely lead to a reduced amount of viable data for ASD subjects in the experiment proper as *RT*s are mainly interpretable in the light of accurate responding.

Methods

Participants

Typically developing children (n=22, age 10-15 years, mean=10.96, median=11) were recruited from a local primary school, and from an email sent to staff working in the school of Philosophy, Psychology and Language Sciences at The University of Edinburgh. An equal number of neurotypical adults (aged 21-59 years, with the majority aged 21-27 years) were also recruited, by word of mouth. All participants had normal or corrected to normal vision.

Stimuli

Participants responded to a hand drawn cartoon tiger, shown in Figure 1. The stimulus was based as closely as possible on a circle, so as the shape was optimally symmetrical and did not cause the subjects to be drawn to any one part of the outline. Also, the features of the tiger were simple, minimalistic and symmetrical, so as to discourage local processing of intricacies of the design.

Although the processing of and attending to faces has been found to be problematic in ASD, Rosset et al (2008) found that ASD and TD children respond in similar ways to

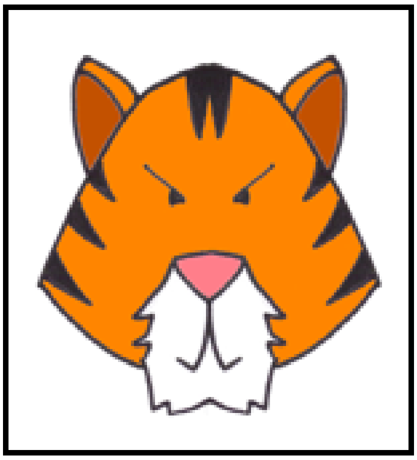

Figure 1: Tiger target used throughout the game

cartoon faces. These findings suggest then that both groups should process the stimuli used in the present study in a similar manner.

A Google images search found a photograph of a jungle scene to serve as a background for the tigers. The background used throughout the game is shown in Figure 2.

Figure 2: Jungle background used throughout the game

Using the tiger image and the jungle photograph, Matlab (The Mathworks) was used to create videos simulating looming movement of two identical tigers toward the participant, with one becoming faster than the other. The Matlab script used to generate the videos is given in Appendix A and has been further annotated to better explain each step.

Creating the videos

Movement of the tigers

A number of variables pertaining to the apparent movement of the tigers were manipulated, including the initial velocity of the tigers, acceleration of the faster tiger and the point at which the tiger accelerates. From this point on, these will be referred to as u, a and *accstart* respectively (this is also how they are referred to in the Matlab script.)

How the video looks

Both tigers are always positioned with the centre of the tiger image at the centre of the Y-axis; each positioned 25% of the screen width in from the sides along the X-axis. The positioning is illustrated in Figure 3.

Figure 3: Positioning of the two tigers

In each video, both tigers start at a uniform velocity, in the positions described and illustrated above. The video begins with both tigers already at this speed: it is assumed that they have come from rest, accelerated and then the velocity has leveled-off, and it is only after the plateau that the video begins. After a set number of frames (this varied and is described in Table 1 under '*accstart*') one tiger begins to accelerate at a constant rate ('a', also detailed in Table 1), continuing to do so throughout the rest of the trial, while the second tiger maintains the original velocity ('u', again, detailed in Table 1).

Changes in the perceived distance, speed and scaling factor for the accelerating tiger is shown in Figure 4.

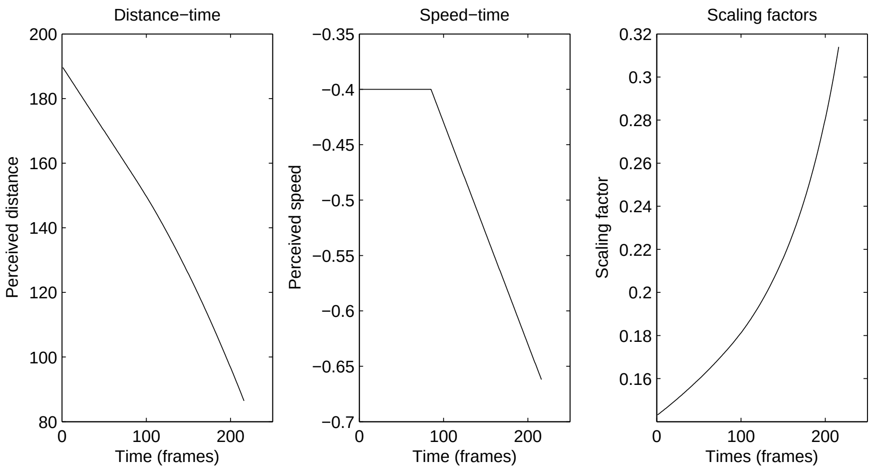

Figure 4: Perceived speed, distance and scaling factor for the accelerating tiger through the course of a video. Note: Speed is shown in negative numbers as the tiger is moving toward the viewer

u	a	accstart
0.4	0.002	0.2
0.4	0.002	0.3
0.4	0.003	0.2
0.4	0.003	0.3
0.2	0.002	0.2
0.2	0.002	0.3
0.2	0.003	0.2
0.2	0.003	0.3

Table 1: Permutations of u, a and accstart. Note: these values are in unspecified units

Mathematical working for simulating the movement according to the variable values outlined above

The aim was to simulate the tigers approach with initial speed (u_0), acceleration (a) and temporal point of acceleration ($accstart$) as described above.

We can simulate this by scaling the tiger in each frame, thereby creating a looming effect. First, the perceived distance of the tiger in each frame for a given set of a, u and $accstart$ was calculated. Secondly a scaling factor was calculated so that the size of the tiger could be adjusted in order to simulate the correct distance in each frame.

Calculating distance

Size changes differentially relative to distance when an object is moving but not accelerating compared to when an object is moving with acceleration. The following equations are used for these two cases:

In the special case of no acceleration (that is, constant speed: a=0)

$$s = s_0 - u_0 t \tag{1}$$

with t=frames and s=distance. s_0=initial distance and was arbitrarily set to 190

So for frame 1

$$s = 190 - (0.4 \times 1)$$
$$s = 189.6$$

For frame 100

$$s = 190 - (0.4 \times 100)$$
$$s = 150$$

In the case of acceleration

$$s = s_0 - (ut + 0.5a(t - accstart)^2) \tag{2}$$

Where t=time, a=uniform acceleration. Note that $accstart$ is expressed in frames. Again, s_0 is arbitrarily set to 190.

Each video contains 216 frames, so if accstart=0.2 then acceleration will begin at frame 43

So for the first frame of acceleration,

$$s = 190 - (0.4 \times 43 + 0.5 \times 0.002 \times (43 - 43)^2)$$
$$s = 190 - (17.2 + 0.001)$$
$$s = 172.799$$

For the tenth frame of acceleration

$$s = 190 - (0.4 \times 53 + 0.5 \times 0.002 \times (53 - 43)^2)$$
$$s = 190 - (21.2 + 0.1)$$
$$s = 168.7$$

For the 12th frame of acceleration (i.e. after 0.5 second of acceleration)

$$s = 190 - (0.4 \times 55 + 0.5 \times 0.002 \times (55 - 43)^2)$$
$$s = 190 - (22 + 0.024)$$
$$s = 167.976$$

For the 24th frame of acceleration (i.e. after 1 second of acceleration)

$$s = 190 - (0.4 \times 63 + 0.5 \times 0.002 \times (67 - 43)^2)$$
$$s = 190 - (25.2 + 0.576)$$
$$s = 164.224$$

For the 36th frame (i.e. after 1.5 seconds of acceleration)

$$s = 190 - (0.4 \times 79 + 0.5 \times 0.002 \times (79 - 43)^2)$$
$$s = 190 - (31.6 + 1.296)$$
$$s = 157.104$$

As we can see, if we increase the number of frames in increments of 12, the value of s does not increase at a constant rate, highlighting the uneven increase in size when we perceive things to be moving toward us (the size increase becomes more evident toward the end of the movement).

a) $0 \rightarrow 12$=22.024
b) $12 \rightarrow 24$=25.776
c) $24 \rightarrow 36$=32.896
a to b is 117% increase in distance, while b to c is 128% increase.

The values of s (distance) calculated above are now used to calculate the scaling factors required to appropriately scale each consecutive frame to simulate the tiger approach. To simulate a tiger that does not accelerate, the first formula for s is used (1). To simulate a tiger that accelerates after a certain point, the second formula for s is used (2).

Calculating scaling factors

Let r be the radius of the tiger at its initial distance. See Figure 5.

Figure 5: Radius of the tiger at initial distance

r is now used to calculate the change in visual angle as the tiger's approach is simulated. A change in visual angle is analogous to a change in perceived size.

Figure 6 illustrates what is being simulated (from a third person perspective).

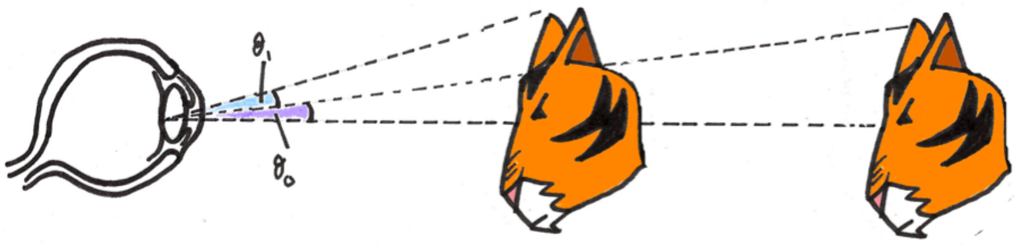

Figure 6: Visual angle relative to perceived distance

As the tiger represents an object, it is subject to size constancy, i.e. apparent size increase is interpreted as approach. However, note that as the tiger (or object) moves toward you, the visual angle increases, using the following formula. The observer will see images of varying size but always from the same distance.

Calculating visual angle

$$tan\theta = \frac{opposite}{adjacent}$$
$$tan\theta = \frac{r}{sn}$$

It is possible to calculate the visual angle for any $tan\theta$. This information can now be used to calculate the scaling factor needed for each frame to accurately simulate looming motion.

The visual angle for the first frame is

$$tan\theta = \frac{r}{s_0}$$

As the frame number increases (i.e. the tiger is perceived to be closer) the radius of the tiger is now referred to as Fr, with F=scaling factor. See Figure 7.

So,

$$tan\theta = \frac{r}{s_n} = \frac{Fr}{s_0}$$

r/s_n is when we are referring to the perceived approach of the tiger and Fr/s_0 is what is actually happening to the tiger: the image is actually getting bigger, while remaining in the original position (i.e. maintaining the original distance from the observer: s_0).

So, if

$$\frac{r}{s_n} = \frac{Fr}{s_0}$$

this implies that

$$\frac{1}{s\,n} = \frac{F}{s_0}$$

which implies that

$$F = \frac{s_0}{s_n}$$

This can then be written as

$$\text{Scaling factor } (F) = \frac{initialdistance(s_0)}{initialdistance{+}1(s_n)}$$

or in other words,

$$\text{Scaling Factor}{=}\frac{simulateddistancefromobserveratframe1}{simulateddistancefromobserveratframe2}$$

This scaling factor is calculated for every frame by dividing the distance in the previous frame by the distance in the current frame, so

$$F = \frac{s_{frame1}}{s_{frame2}}$$

$$F = \frac{s_{frame2}}{s_{frame3}}$$

$$F = \frac{s_{frame(n)}}{s_{frame(n+1)}} \text{ etc}$$

Figure 7: The radius is now referred to as Fr

We have now calculated everything we need to create accurate looming motion. These formulae were written into the Matlab script alongside the values of a, u and $accstart$ detailed in Table 1. Scaling factors were calculated for every frame in Matlab and the tiger image was adjusted accordingly before being played back-to-back as an animation.

A worked example will now be given using permutation 1 of Table 1. Scaling factors for frame 200 of a version of the motion with and without acceleration will be calculated.

Worked example a)

Permutation 1 with acceleration

u=0.4
a=0.002
$accstart$=0.2

Calculating distance:

$$s = s_0 - (ut + 0.5a(t - accstart)^2)$$

First we must calculate $accstart$ in frames. There are 216 frames in total so

$$0.2 \times 216 = 43.2$$

This is rounded to 43 frames.

$$s = 190 - ((0.4 \times 200) + (0.5 \times 0.002 \times (200 - 43)^2))$$
$$s = 190 - (80 + 24.629)$$
$$s = 85.371$$

Calculating scaling factor:

$$F = \frac{s_0}{s_n}$$

$$F = \frac{initialdistance}{currentdistance}$$

$$F = \frac{190}{85.371}$$

$$F = 2.226$$

Worked example b)

Permutation 1 with no acceleration

u=0.4
a=0
$accstart$=0

$$s = s_0 - (ut + 0.5a(t - accstart)^2)$$

$$s = 190 - ((0.4 \times 200) + (0.5 \times 0 \times (200 - 0)^2)$$
$$s = 190 - 80 + 0$$
$$s = 110$$

$$F = \frac{s_0}{s_n}$$

$$F = \frac{190}{110}$$

$$\text{F} = 1.727$$

As we can see, at the same chronological point in the video (frame 200), the tiger that has accelerated has a larger scaling factor than the tiger that maintains its initial speed. This means that for this frame the tiger that accelerates appears larger, and therefore closer, than the tiger that does not accelerate.

Each frame of the animation was created using this formula. The videos were made by taking an original image and scaling it 216* times, according to the scaling factors derived from the formula above. This modeled the perceived changes in size that would result for any values of u, a and $accstart$.

*The animation is created with 24 frames per second, and each video has a 9 second duration: $24 \times 9 = 216$.

24 frames/second was chosen as a frame rate so that the scaling of size was smooth and better simulated looming: the higher the number of frames shown each second, the smoother an animation will look.

Problems encountered with videos

Due to an unidentified problem with Matlab, there are 5 videos in which the faster tiger is on the right and 4 videos in which the faster is on the left. The bias occurred because a number of videos were of too poor a quality to be used. All videos were made using a single script with a loop written into it so that the single script could generate a large number of videos, each with specific permutations of the key variables. There were no errors given in Matlab and both good and poorer quality videos were made from the same script. The variability in quality may have been due perhaps to compression codec problems. The problem occurred sporadically throughout the use of Matlab. The script was re-run with the loop edited to include only single videos that had been poorly produced and some of these were reproduced and were of a good enough quality, others were not. Due to time restrictions and the sporadic nature of this compression problem, it was decided that the videos that had been produced successfully were sufficient in providing a large enough number of permutations of the main variables to choose from. The slight right bias was thought to have little potential impact on the outcome of the pilot, as no specific hypothesis regarding hand used was made.

Problems encountered with equipment

Due to unforeseen computer problems, the input device (the way in which subjects responded to stimuli) had to be altered for subjects not being tested in the university. The laptop being used to run the experiment had been set up to work with the SR (serial response) box, however, an unexplained problem with the driver for the SR-box installed on the laptop meant that the use of the SR-box was no longer possible. It was felt that given previous problems with E-Prime and incompatibility with hardware, it was best to alter the input device than to wait for the laptop to be fixed. The input device on the laptop was changed to the mouse buttons. Although this produces less accurate response times than the SR-box, it was felt that for the pilot, where only a trend is needed to identify ceiling or floor effects, this was the most appropriate course of action. Also, since the majority of subjects were tested on the laptop, the additional time added by the mouse response was the same for the majority of subjects.

For participants tested at the university, testing was carried out in the Human Cognitive Development lab using a HP Compaq desktop PC, with a 42.5×27.5cm monitor and the SR-box was used as the input device. (It was important to keep the SR-box as the input device for some subjects as this was the preferred method of responding for the proper experiment, therefore piloting this method was important, even if it was not implemented for all subjects.) For participants tested at school, the experiment was run on a Dell laptop and testing took place in a quite room. Adult participants not tested at the university were tested in a mutually convenient location and always in a quiet environment. They also used the Dell laptop.

Procedure

Participants sat at the computer in a comfortable position approximately 40cm from the monitor. They were requested to rest their hands on the SR-box (desktop) or mouse buttons (laptop) so they could comfortably use one finger from each hand per button. (When using the SR-box the outermost two buttons were used and the middle three were securely covered to ensure subjects only used and rested their fingers on the correct buttons). Participants were told the premise of the game as follows:

> "Two tigers will run towards you and you have to stop the faster one as soon as you can. At the start they'll both be going the same speed, so if it was a race it would be a tie. Then one of them is going to get faster and pull ahead. <This was reinforced with actions showing the experimenter's hands both moving forward at a uniform speed then one speeding up while the other maintains the original speed>. As soon as you can tell which one is going faster, press the button on the same side as the faster tiger. So, if the faster one is on the right, press the right button <pointed to right of screen and right button>. If the faster one is on the left, press the left button <pointed to left of screen and left button>."

Participants completed 40 trials in a random order with each testing session lasting less than 10 minutes.

Results (pilot)

Problems encountered with data recording

Due to an unidentifiable problem with the laptop (a suspected memory leak), on a small number of occasions a random video did not play. E-Prime gave no error so finding the source of the problem was not possible. It did not appear to occur reliably at any given point in the experiment and was not consistently the same video. When this error did occur, it only ever happened once during the course of the session. When this occurred the right mouse button was pressed by the experimenter and the experiment continued as normal. These trials were easy to find in the data file as the *RT*s were much longer than usual. All of these trials were removed from the data set. Less than 1% of trials were removed for this reason.

How the raw data was prepared for analysis

Accuracy and *RT* were analysed separately. Accuracy was analysed to see if any permutations of variables were significantly more difficult than others. Any which were found to be too difficult would not be included in the experiment proper.

Only *RT*s from trials in which the correct response was given were analysed, providing the response was made *after* the acceleration of the faster tiger. These trials had a positive relative *RT*. (Accuracy data also only included those trials with a positive relative *RT*). Trials in which the button was pressed preemptively were not included.

Any *RT* that fell 2SD from a subject's mean was excluded (Borghi and Scorolli, 2009) and replaced with that subject's mean *RT*. Once data for each subject had been cleaned, any individual whose mean *RT* exceeded 2SD from the group mean was excluded.

Results (pilot)

Table 2 shows the accuracy rates and mean *RT* for the adult and child group for each video. The results are also shown graphically in Appendix C in Figures 22 and 23.

Video (side of target, a, $accstart$, u)	Adult accuracy (%)	Adult mean RT (ms)	Child accuracy (%)	Child mean RT (ms)
L224	88	3892	92	4816
L234	86	3826	85	4921
L332	95	4807	100	5077
R222	95	5195	99	6247
R232	91	5066	97	5756
R322	96	4754	98	5419
R324	91	3462	96	4460
R334	93	3168	95	4014

Table 2: Accuracy rates and mean *RT*s for pilot study

A univariate ANOVA was performed for the adult group and child group separately. Mean *RT*s for each video were entered into analysis as the dependent variable, with video as the fixed factor. For the adult group there was a significant effect of video on mean (relative) *RT*: $F(7, 166) = 6.626, p < 0.001$. Pairwise comparisons revealed a significant difference between a number of the videos.

There was also a significant effect of video on mean (relative) *RT* for the child group: $F(7, 168) = 12.401, p < 0.001$. Again, pairwise comparisons revealed significantly different *RT*s between a number of the videos.

Discussion (Pilot)

Every video met the criteria set out previously, with the target being identified at least 80% of the time by both groups. With accuracy rates ranging from 85-100% it is clear that some videos are more challenging than others and this is also reflected in the significant difference in mean *RT* between some of the videos.

As all of the videos used in the pilot study had an accuracy rate >80%, all of these iterations of a, u and *accstart* were included in the final condition of the experiment proper. In order to remove the bias toward the target being presented on the right, R334 was changed to L334 for the experiment proper. It was not thought that altering the target side would significantly affect the difficulty of this particular iteration of the key variables.

Experiment Proper

Methods

Participants

12 children with ASD (11 years−12 years, 1 month; mean age=11 years, 8 months) and 12 chronological age (CA) and gender matched controls (10 years, 11 months−12 years, 2 months; mean age=11 years, 6 months) participated. All of the ASD children had a confirmed diagnosis of autism or Asperger syndrome by a medical professional. Only 2 of these children were currently in mainstream education. Intellectual functioning was assessed using the nonverbal subtests (NVI) of the revised Kaufman Assessment Battery for Children (W-ABC-II). The mean standard score on the NVI for ASD and TD subjects were 91 (range: 57-107) and 98 (range: 68-130) respectively. The Standard Score is a scaled equivalent of the raw scores for each individual subtest, normalising for age. This ensures that older children are not obtaining a higher score by virtue of being older. All children had normal or corrected to normal vision and all passed a test of stereoscopic vision.

Design

The experiment contains five distinct tasks, each with a different repeated measures design.

Task 1: Centre detection

This was a simple detection task following a 3*2 design. Independent variables were hand used (dominant, nondominant) and fixation duration (the length of time between target presentations: 500ms, 1000ms, 2000ms).

Task 2: Side detection

This followed a similar design to Task 1. The target was now presented laterally (so either congruent with the dominant or nondominant hand). The second independent variable was target size (small, medium, large). Again, this task follows a 3*2 design.

Task 3: Static discrimination

This was a static discrimination task. As with the previous tasks, hand used (dominant, nondominant) was an independent variable and the task-specific independent variable was comparison pair (small vs. large, medium vs. large, small vs. medium). This task therefore also follows a 3*2 design.

Task 4: Single dynamic change detection

This task involves a single dynamic stimulus. It follows a 2*8 design. Again, hand used (dominant, nondominant) was an independent variable. The second independent variable was the video shown in each trial. In each video, three variables related to target speed and acceleration were altered. Each of these variables had two levels. Within each video the side of target presentation was also manipulated. Each video then had a 2*2*2*2 design.

Task 5: Dynamic discrimination

This task involves two dynamic stimuli and follows the same design as Task 4.

Task order was fixed, although trial order within each task was randomised. Basic task design is summarised in Table 3.

Task	Number of stimuli	Positioning of stimuli	Static or dynamic stimuli
1	1	centre	static
2	1	right/left	static
3	2	right and left	static
4	1	right/left	dynamic
5	2	right and left	dynamic

Table 3: Summary of the basic design of the five tasks

Stimuli

As described above, the game was made up of a number of different tasks, however the basic stimulus and background (the tiger image and the jungle photograph) were used in each condition and were unchanged from the pilot. The versions of the stimuli used for each task within the game are described below and also summarised in Table 4 and Table 5 alongside a screenshot.

Static stimuli

The original tiger image (originally used to create the pilot videos) was used for tasks 1, 2 and 3.

In task 1 the image was 21x23mm. (This refers to the image size on-screen during the game.) It was presented in the centre of the screen, with the centre of the image occupying the horizontal and vertical centre of the screen.

In tasks 2 and 3 the image was resized twice, giving a 'small', 'medium' and 'large' target. These measured 21×23mm, 24×26mm and 28×30mm respectively. The image was presented with the centre of the image on the vertical centre of the screen, either 1/4 of the screen width from the right or left edge.

Dynamic stimuli

The videos used in the pilot were used for the final task (task 5), with the exception of R344, which was changed to L344.

Videos using the same variable permutations were made for task 4, showing only the faster tiger. These videos were made in a very similar way to the pilot videos.

Note, from this point on, the five tasks will be described as follows:

Task 1: Centre detection

Task 2: Side detection

Task 3: Static discrimination

Task 4: Single dynamic change detection

Task 5: Dynamic discrimination

Task	Instruction from narrator	Description of stimuli on screen after instruction	Task-specific variable	Screenshot
Centre detection	"Press any button *as soon* as you see the tiger"	Tiger in centre of screen on jungle background.	Fixation duration (500ms, 1000ms, 2000ms)	
Side detection	"Press the button on the *same side* as the tiger"	Tiger presented in vertical centre of the screen, positioned 0.25 of the length of the background from the right or left edge.	Size of target (small, medium, large)	
Static discrimination	"Which tiger is bigger? Press the button on the *same side* as the *bigger* tiger"	One tiger (size a, b or c) was positioned 0.25 of the length of the background from the right edge. Another (size a, b or c) 0.25 from the left. The centres of both tigers were positioned in the vertical centre. Note the tigers were never both the same size so the possible permutations were a-b, a-c, b-c for the left and right.	Comparison pair (small vs. large, medium vs. large, small vs. medium)	

Table 4: Summary of the basic design of the three static tasks

Task	Instruction from narrator	Description of stimuli on screen after instruction	Task-specific variable
Single dynamic change detection	"The tiger is going to run towards you. At first he'll keep going the same speed, *then he'll get faster*. As soon as the tiger gets faster, press the button on the same side as the tiger. Let me show you"	Tiger positioned as for 'side detection', with it 'looming' towards the player. The image is resized each frame to give the illusion of looming. The rate at which the image is resized changes after a set number of frames (*accstart*), to give the illusion of acceleration.	Video (8) Within each video a (acceleration: 0.002, 0.003), u (initial speed: $0.2, 0.4$), *accstart* (point at which acceleration begins: 0.2, 0.3)
Dynamic discrimination	"Now we're going to try to stop the most *dangerous* tiger. It's the one that's coming *faster* and will reach you first. *As soon* as you can tell which one is coming faster, press the button on the *same side* as that tiger. Shall we practice?"	As above, with two tigers occupying the positions described for 'static discrimination'. One behaves as described for 'single dynamic change detection'; the other appears to move at a constant speed.	As above.

Table 5: Summary of the basic design of the two dynamic tasks

Feedback animation

A feedback animation sequence was created using hand drawn frames and GIMP computer software (The GNU Image Manipulation Program).

The feedback animation sequence is shown to participants when the correct answer is given in the dynamic discrimination task. It shows a hand held out in a 'halt' position (a right hand on the right of the screen for trials in which the faster tiger is on the right, left hand on the left of the screen for trials in which the correct answer is left). The idea of the hand signalling a 'stop' command is reinforced with "stop" being shouted by the narrator of the game. We then see the two tigers, the faster stopped with his hands in the air as if surrendering, and the slower on the other side, front paws screeching on the ground as he tries to slow down. The slower tiger continues to slow himself down as the faster tiger turns 90 degrees and falls backwards, as if from shock. The faster tiger now blocks the path of the slower tiger as he hits the ground. This animation is hoped to reinforce a consequence for stopping the faster tiger: by stopping the faster tiger you are preventing both tigers from reaching you as the faster tiger blocks the path of the slower one. Note that like the hand, the two tigers are always shown on the side of the screen that is true to their positioning in the trial in order to keep a logical flow in the game. A storyboard showing the frames used in the animation along with the narration is shown in Figure 8.

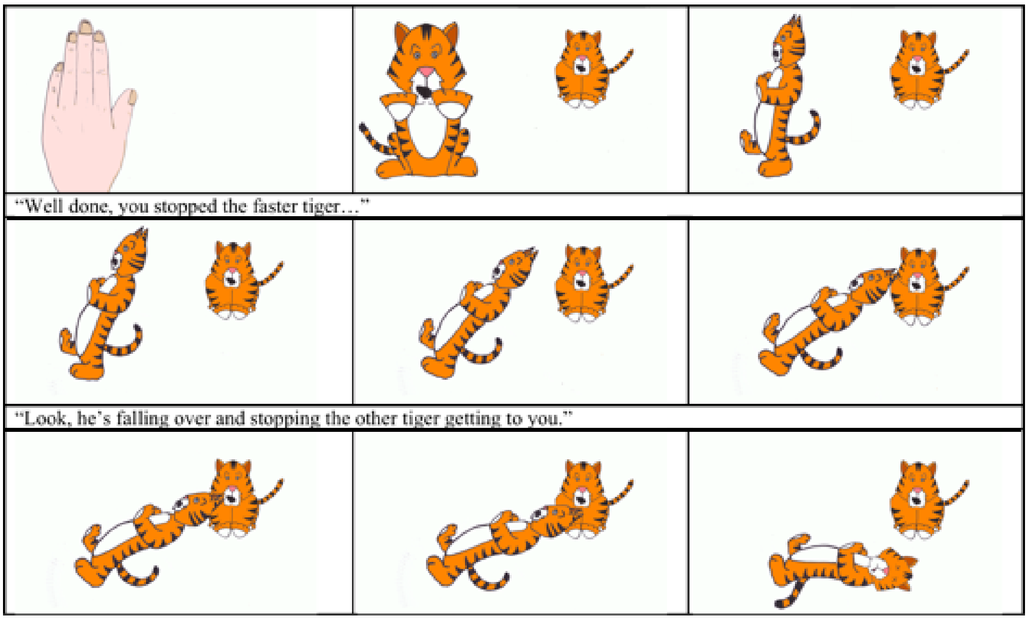

Figure 8: Storyboard for feedback animation for correct responses

Procedure (IQ test and stereovision test)

Children were administered the NVI (non-verbal IQ test) and TNO stereoscopic vision test before completing the computer game in a different session. This initial session lasted approximately an hour and breaks were given when necessary. Testing took place in a quiet room during class hours.

Procedure (computer game)

As with the pilot study, testing environments were replicated as closely as possible in all testing locations. Participants completed the tasks in a quiet room, using the desktop computer used in the pilot study for participants tested in the lab. The experimenter briefed the child, explaining that there were a variety of tasks, and each would be explained in the game. It was made clear that although instructions were given in the game, children were free to ask questions at any point during the game. Children were asked to use both hands to use the SR-box, with a finger from the right and left hand resting on the first and fifth buttons (the first and last buttons in the row of five. As was the case in the pilot, the middle three buttons were covered with tape and it was reinforced that only the two uncovered buttons worked).

Participants sat at the computer and listened to the instructions given by the game's narrator. These instructions were also presented simultaneously on screen (shortened if necessary) for those children able to read them.

The procedure for each task will now be detailed separately.

Centre detection

Participants are prompted by the game's narrator to press any (uncovered) button on the SR-box (so, the two outermost buttons) as soon as they see a tiger. Note that this task was in two parts: for the first half children were asked to use their dominant hand on the corresponding button (so the right-most button using the right hand for a right handed child). After 12 trials a white screen was shown and the child was instructed to use the other hand for the remaining 12 trials and they were told that the task was still the same. The experimenter initiated the second half once the child understood the instructions.

The tiger was presented in the centre of the screen on the jungle background and remained on screen until a response had been made. The target was presented in place of the fixation cross randomly after three different durations: 500ms, 1000ms and 2000ms, so as participants were not able to respond rhythmically, as they would do if targets were presented every 500ms after a response. Varying the duration between target presentations was hoped to ensure sustained attention on the task. The duration between target presentations will be referred to as 'fixation duration' from this point.

Side detection

The narrator introduced the side detection task by explaining that players must "press the button on the same side as the tiger, as soon as you see it." The tiger was presented either to the left or right of the central fixation point. Its positioning was in the vertical centre and positioned 25% of the width of the screen from the fixation point and the edge of the screen. Again the tiger was placed on the jungle background. The target was presented successively at a constant rate after each response (500ms), with side of presentation and target size randomised. Targets were small, medium or large (exact dimensions detailed above). Again, the two outermost buttons were used to respond, and the button pressed must correspond to the side on which the target is presented in order for the *RT* to be included in final analysis. Participants completed 12 trials.

Static discrimination

The small, medium and large tigers used in the previous task were presented simultaneously in pairs, one each in the left and right positions described above. Trials always contained a relatively larger tiger. There was no trial in which, for example, small was paired with small. The three comparison pairs therefore were small vs. large, small vs. medium and medium vs. large. The larger tiger of a pair was presented randomly on the right or left and the order in which the pairs were presented was also randomised. Participants were instructed to press the button on the same side as the larger tiger, using the SR-box as previously instructed. Participants completed 18 trails.

Single dynamic change detection

In this baseline condition subjects pressed the button on the same side as a single looming tiger, positioned to the left or right of fixation as described above, as soon as it appeared to move faster toward them.(As described above, the tiger is initially moving at a constant rate and then begins to accelerate). The videos were preceded by a demonstration video, in which the narrator shouts "Now! Did you see the tiger speed up?" at the point at which the tiger begins to accelerate. Eight videos were included (essentially the same videos as used in the pilot and the final task, without the slower tiger). 24 video trials were shown in a randomised order, within the constraint that the tiger should alternate from right to left. If the videos were randomised without this constraint then often the tiger would be shown to loom from the right twice in a row and if the response had been made when the image was still relatively small, then it was at times difficult to see that a new trial had begun.

If a response was made before the tiger had accelerated (and was still maintaining it's initial speed) then the narrator warned that it was "still too soon to tell!" and the next trial began.

Dynamic size discrimination

As with the pilot, subjects stopped the faster of two tigers approaching them head-on. The tigers were positioned to the left and right of centre as described above and their movement was as described for the pilot. Trials were presented in 3 blocks of 8, preceded by 4 practice trials, which were not be included in analysis. During the practice trials, the feedback animation described earlier was shown after a correct response, alongside the narrator's commentary "Well done, you stopped the faster tiger! Look, he's falling over and stopping the other tiger from getting to you." For proper trials, the animation was sped up and the narration was not included. In both practice and proper trials, incorrect responses were accompanied by " Oh no! You picked the wrong tiger!" and this was also written on screen. After each block (both practice and proper), a score was shown on screen (e.g. "Ben 3-Tiger 4") and this was accompanied by either "Well done, you won!", "Oh no, the tiger won!" or "It's a tie!". In order to try to keep children interested, they were invited to try to beat their score at the end of each block.

Stills from the three static tasks and a brief description of all tasks has been detailed above in Figure 4 and Figure 5.

Results

Data was analysed twice, both times with a different measurement of central tendency used to convert the raw data into the data entered into analyses. The first analysis used subject medians for each condition and the second used the subject means for each condition, with outliers excluded. These two methods are described in more detail below.

Medians

The use of medians was initially the preferred method as it is theoretically more resistant to high variance than the mean and negates the necessity to remove outliers. It was thought that rules to remove and replace outliers might reduce the valid variability of subjects' response times. Identifying outliers based on a measurement that uses the mean would be inappropriate, as the high level of variance would skew the mean. For this reason, using standard deviation as an indicator of outlier data was not used.

However, when calculating a representative value for each of the smaller variables for each subject (for example, their representative RT when $a = 0.002$) using the median, this was clearly not the most appropriate method. Often the median of three values was calculated, and with true outliers (not representative of normal variability) still in the dataset, the results from this analysis were felt to not be a true reflection of the results. For this reason, the individual's mean was used in place of the median. Results regarding group effects on RT from the original analysis are given in Appendix B. Accuracy was to be analysed after the analysis of RT, however analysis of accuracy was not carried out on the median data as the decision had already been made to re-analyse using the mean.

Means

Having identified a problem with outlier individuals in the first analysis, outliers were removed in the second analysis. This was first done at the subject level (removing data points that were deemed outliers for the subject's data set for that condition) and secondly at the group level (removing individuals from certain conditions). Data cleaning is detailed fully below.

Data cleaning

Note: data was always considered on a condition by condition basis, so "subject's mean" refers to their mean only in the current condition, not the mean across all five tasks.

For each subject in each task, any RT data point that exceeded 2 standard deviations from that subject's mean (in either direction, i.e. mean+2SD or mean−2SD) was deemed to be an outlier (Borghi and Scorolli, 2009). These data points were replaced with the mean of the remaining data for that subject in the given task.

Individual outliers were defined as any participant whose total mean for the given condition was more than 2SD from the group (ASD or TD) mean. Any outlier participants identified were excluded from analysis of that condition. No one participant was removed from every condition, with every child able to perform at least 3/5 of the tasks in the normal range for their developmental group. One ASD subject was removed from the side detection and static discrimination tasks and one TD subject was removed from the centre detection and single dynamic change detection tasks[1].

Reaction time data

The RT data from the first three conditions could be used at face value, however dynamic conditions required the RTs to be recalculated as described below.

Reaction times (RT) were recorded from the start of each trial. This RT is referred to as $RT_{absolute}$. From this, the true reaction time (the time to elapse after the faster tiger begins to accelerate), is referred to as $RT_{relative}$ and is calculated as follows:

$$RT_{relative} = RT_{absolute} - (\text{video duration} \times accstart)$$

Where video duration=9000ms and $accstart$ is the fraction of the video duration after which the faster tiger begins to accelerate.

So for $accstart = 0.2$:

$$RT_{relative} = RT_{absolute} - (9000 \times 0.2)$$
$$RT_{relative} = RT_{absolute} - 1800$$

So, for the example above, if

$$RT_{absolute} = 6700$$

then

$$RT_{relative} = 6700 - (1800)$$
$$RT_{relative} = 4900.$$

[1]These two participants were not unusual with respect to IQ relative to the rest of their respective group.

The child responded 4900ms after the faster tiger started to accelerate (or after the single tiger began to accelerate in the case of single dynamic change detection).

If $RT_{relative}$ was negative, this indicates that the button was pressed preemptively, and these trials were not included in analysis.

For analysis of RT, only correct responses with a positive $RT_{relative}$ were included in analysis.

Accuracy

As for RT, only trials with a positive $RT_{relative}$ were included in analysis of accuracy, as it would be illogical to investigate the accuracy of preemptive responses.

How the data will be analysed

Data will first be analysed on a condition-by-condition basis, working chronologically through the game.

Accuracy rates for each group will be expressed as a percentage, followed by the appropriate analysis (ANOVA or nonparametric equivalent) in conditions where rates differ greatly between groups. Note that accuracy rates are not given for the centre task as the correct button was specified at the start of each of the two blocks.

RT analysis was broken up into the following tests: Shapiro Wilks test of normality; analysis of covariance to assess potential hand and IQ effects; final analysis including the task specific variables (e.g. target size) and IQ as a covariate where this was deemed appropriate (according to results from the initial covariate analysis). A covariate was only used where appropriate so that power was not being unnecessarily reduced by the use of a covariate. In cases where the effect of IQ is dubious, perhaps due to a p-value approaching significance coupled with low observed power, analysis both with and without the covariate will be discussed.

If normality checks show that data from one of the two groups is not normally distributed then nonparametric tests will be used in the final analysis of group differences. In the final analysis, if the majority of the task-specific variables for either group are not normally distributed, then nonparametric tests will be used. In cases where a covariate is deemed necessary, this rule will not apply, as there is no widely used method for conducting nonparametric analysis with a covariate.

Once each condition has been analysed individually, a number of conditions will be directly compared, in order to try to pinpoint areas of relative difficulty for either group.

Intelligence as a covariate

Results from the K-ABC-II were calculated as an IQ Standard Score and this was entered as the covariate, where appropriate. The Standard Score is calculated by taking raw scores from each task in the NVI and obtaining a scaled score, so the score becomes independent of participant age. The sum of the scaled scores is then transformed into a standard score and a percentile rank.

See Appendix D for a table showing subjects' standard scores and percentile ranks.

Age matching

Participants were tightly age-matched within a narrow age range. For this reason age will not be analysed as a covariate.

Condition-by-condition analysis

Centre: detecting the onset of a static centred image

- Fixation duration (500ms, 1000ms, 2000ms)
- Hand used (variable manipulated by instruction)

A number of mean *RT*s were calculated for each subject and entered into analysis: an overall mean *RT* with all variables (hand and fixation duration) collapsed; overall mean *RT* calculated separately for the dominant and nondominant hand (fixation duration collapsed for both); an overall mean *RT* (both hands collapsed) for each of the three fixation durations; an overall mean *RT* calculated separately for both hands for each of the three fixation durations.

Normality

For the ASD group, data was found to be not normally distributed for 1000 dominant and for the TD group data deviated from a normal distribution for 2000 mean. All other data was normally distributed.

As the variables to be entered into covariate analysis (total mean, dominant mean and nondominant mean) were normally distributed for both groups, parametric analysis will be conducted to assess the contribution of IQ to group differences. Parametric analysis will also be used to assess the effect of fixation duration and hand between groups as 5/6 of the variables concerned were found to be normally distributed.

Is IQ making a significant contribution to variance?

A 2*2 repeated measures ANCOVA was performed using subjects' overall means for the two hands as within-subjects factors, group (ASD, TD) as a between-subjects factor and IQ

Standard Score as a covariate. Main effects were compared using the Bonferroni adjustment for multiple comparisons. (This is true for all subsequent analyses in all conditions.)

IQ was found to have no significant effect on RT. To verify this finding, a univariate ANCOVA was performed to assess the contribution of the two hands combined, with total mean as the dependent variable, group as the fixed factor and IQ as the covariate. As expected there was no significant contribution of IQ to variance. For this reason IQ will not be included as a covariate in the final analysis of this condition, in order to conserve power.

Final analysis

A 3*2*2 repeated measures ANOVA was performed using individual subject's mean RTs (with outliers removed as described above). The within-subjects variables were fixation duration and hand used (dominant and nondominant). Group (ASD and TD) was entered as a between-subjects factor.

There was no significant effect of fixation duration and no interaction of fixation duration and group. The difference between fixation durations was greatest between the longest and shortest duration, however as stated previously, this difference was not significant.

There was a significant effect of hand used: $F(1,20) = 10.058, p < 0.05, P = 0.855$, which did not interact with group. The nondominant hand was significantly faster, with the mean difference between the two hands being 48.772 (Standard Error (SE)=15.378). The means and standard errors for each hand for the two groups are shown in Table 6 below.

Group	Hand	Mean RT (ms)	Standard Error
ASD	Dominant	419.52	27.967
ASD	Nondominant	345.87	15.313
TD	Dominant	303.81	27.967
TD	Nondominant	279.92	15.313

Table 6: Mean RT and Standard Error for both groups for each hand

Mean RTs were found to differ significantly between the two groups, with TD subjects being significantly faster than the ASD subjects: $F(1,20) = 10.575, p < 0.05, P = 0.871$; mean difference=90.831 (SE=27.931).

Figure 9 shows the significant difference between the two groups and also the significant difference between RTs produced by the two hands.

As hand was a significant contributor to variance, data from the two hands will now be analysed separately in this and all subsequent conditions. The hands will be referred to as dominant and nondominant, as opposed to right or left, as this will be more meaningful as the participants are of mixed handedness. Analysing the dominant and nondominant

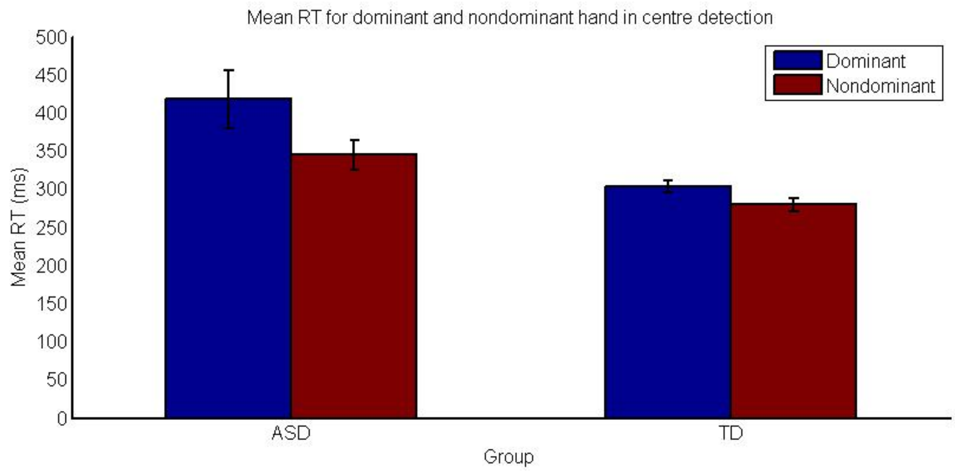

Figure 9: Mean *RT* for the dominant and nondominant hand for each group in the centre detection task. Error bars show Standard deviation in this and all susequent graphs.

hand separately should theoretically both increase power and allow for easier comparisons across conditions.

Dominant hand

Data for the dominant hand was entered into a 3*2 repeated measures ANOVA, with fixation duration as the within-subjects factor and group as a between-subjects factor. The three within-subjects variables failed Levene's Test, therefore nonparametric analysis was performed.

Means for the dominant hand for the three values of fixation duration were entered into a Kruskal-Wallis test as dependent variables, with developmental group as the grouping factor. There was a significant difference between the two groups' *RT*s for the two longer fixation durations (1000ms and 2000ms), although no difference in mean *RT* when targets were shown after 500ms: χ^2 (1, N=23)=4.64, p=0.031 and χ^2 (1, N=23)=4.78, p=0.029 for 1000ms and 2000ms respectively. Means and standard deviations for the three values of fixation duration are shown in Table 7.

Fixation duration (ms)	Group (n)	Mean *RT* (2dp) (ms)	Standard Deviation
500	ASD(12)	398.65	108.47
500	TD(11)	325.63	26.66
1000	ASD(12)	424.12	195.79
1000	TD(11)	290.98	32.20
2000	ASD(12)	398.82	113.21
2000	TD(11)	294.83	31.84

Table 7: Mean *RT* and Standard Deviation for each group for each value of fixation duration

Nondominant

Data for the nondominant hand was entered into 3*2 repeated measures ANOVA, with fixation duration as the within-subjects factor and group as the between-subjects factor. Mean RTs and standard deviations for the three fixation durations are given in Table 8 below.

Fixation duration (ms)	Group (n)	Mean RT (2dp) (ms)	Standard Deviation
500	ASD(12)	346.51	89.25
500	TD(11)	297.21	36.40
1000	ASD(12)	356.45	83.94
1000	TD(11)	268.82	37.03
2000	ASD(12)	334.65	64.97
2000	TD(11)	273.72	33.00

Table 8: Mean RT and Standard Deviation for the three fixation durations for each group using the nondominant hand

Fixation duration did not have a significant effect on RT, however, the three variables failed Leven's test of homogeneity of variance and therefore appropriate non-parametric analysis is given below.

There was a significant effect of group: $F(1,20) = 9.275, p < 0.05, P = 0.826$, with TD again being faster, with an average difference of 65.952 (SE=21.656). Parameter estimates showed group to make a significant contribution to variance in RTs for the two longer fixation durations: $b = 87.63, t = 3.17, p < 0.05$ and $b = 60.93, t = 2.77, p < 0.05$ respectively. Group made no significant contribution to variance in RTs for the shortest fixation duration.

Non-parametric analysis of fixation duration for the nondominant hand

Nonparametric tests were run on all three values of the dependent variable, as they failed Leven's Test of homogeneity of variance in the previous parametric analysis. As with the dominant hand and the analysis above, the Kruskall-Wallis tests found a significant difference between the two groups for the two longer fixation durations: $\chi^2(1, N = 23) = 6.06$, p=0.014 for both 1000ms and 2000ms.

When fixation duration=500ms, for which groups' mean RTs did not significantly differ, RTs from the nondominant hand were further from significance than those from the dominant hand.

Centre detection summary

There was no effect of IQ on reaction times, but group (controlling for IQ) was significant, with ASD being slower. There was a significant effect of hand used, with the nondominant hand being significantly faster than the dominant hand. Group mean *RT*s were significantly different in both hand conditions for the two longer fixation durations, with ASD significantly slower. Responses to target after the shortest fixation duration were equivalent.

Side detection: detecting a single laterally presented target

- size of target (small, medium, large)
- hand used (dominant, nondominant)

Side detection accuracy

The correct response was made on 97% of the trials for the ASD group and 98% for the TD group. Univariate analysis verified that there was no significant difference between accuracy rates for the two groups.

Side detection *RT*

Normality

The vast majority of variables, including the three main variables, were not normally distributed for the ASD group. The exceptions were: large mean and large nondominant mean. The reverse is true for TD, with the majority of variables having a normal distribution of *RT*s across the group, with the following exceptions: small mean and large nondominant mean.

As final analysis will be conducted in order to directly compare groups, the non-normal distribution of the ASD group's data must be taken into account, and it would seem that nonparametric analysis is most appropriate.

Is IQ making a significant contribution to variance?

All variables were entered into a Spearman's test and with 2-tails there were no significant correlations between IQ and any variable. With 1-tail there were two instances in which IQ negatively correlated with RT: medium mean: $r(21) = -0.367$, $p<0.05$ and total mean for the nondominant hand: $r(21) = -0.352, p = 0.05$. As there was no specific hypothesis regarding IQ's role in a target detection task, the outcome from 2-tailed significance testing seems like the most appropriate. It is interesting to note however that there is a significant (one-tailed) negative correlation between IQ and RT only for the *nondominant* hand.

Using a two-tailed hypothesis regarding IQ, final analysis does not appear to require a covariate.

Final analysis

Dominant

Kruskal-Wallis nonparametric tests comparing the two groups for the three values of size showed no significant difference in mean RTs between the two groups when using the dominant hand.

Nondominant

Data for the nondominant hand was analysed as outlined above, which showed a significant difference between groups for every mean RT recorded for the nondominant hand. These are detailed in Table 9 below and shown in Graph 10.

Target size	p-value associated with the difference between groups
Small	0.005
Medium	0.027
Large	0.049

Table 9: p-values for each of the three target sizes

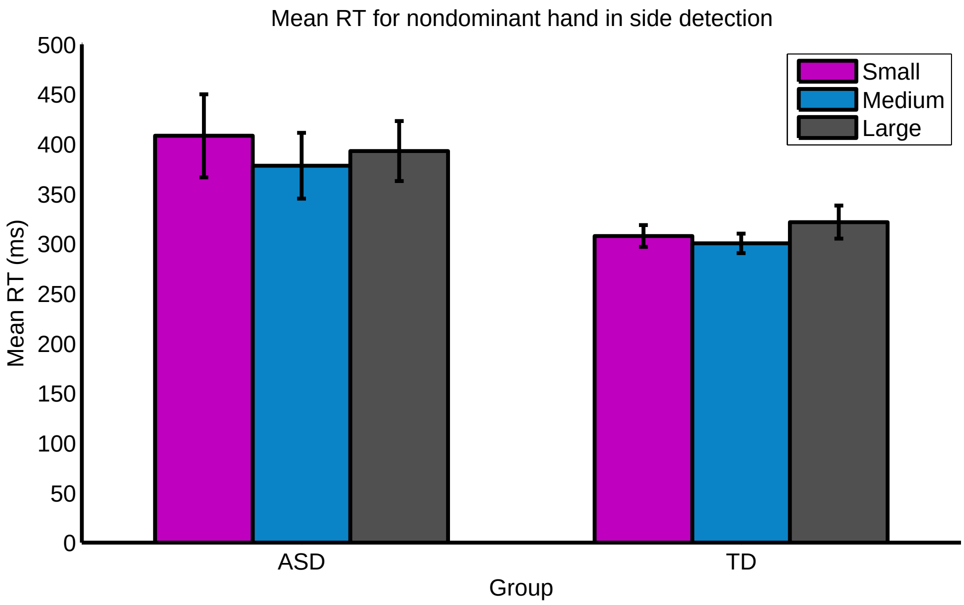

Figure 10: Mean RT for the nondominant hand in side

Side detection summary
In each case the nondominant hand produces RTs that differ significantly between the groups. Group mean RTs are equivalent when responding with the dominant hand.

Detection summary

The first two tasks tested participants' ability to detect stimuli and respond as quickly as possible. When the target was presented in the centre of the screen, TD children responded significantly faster than ASD children, regardless of which hand was used. When detecting stimuli presented to either side of fixation, both groups of children responded equally quickly when using the dominant hand. When using the non-dominant hand, ASD children responded significantly slower to lateral targets than TD children.

The length of time between target presentations (fixation duration) had a significant effect on detection times, although target size appears not to have affected detection *RT*s. Comparison of the two detection conditions will be detailed at a later point.

Static discrimination: which tiger is bigger?

- comparison pair (small vs. medium, small vs. large, medium vs. large)
- hand used (dominant, nondominant)

Static discrimination accuracy

The correct response was made on 93% of the trials for the ASD group and 96% for the TD group. Again this difference was found to be non-significant.

Static discrimination *RT*

Normality

The total mean *RT* for medium vs. large was not normally distributed for TD or ASD (S-W=0.035 and 0.034 respectively), as was medium vs. large for the dominant hand for TD (Shapiro-Wilk: p=0.033) and medium vs. large nondominant for TD (Shapiro-Wilk: p=0.037). All measures of Small vs. large (total, dominant and nondominant) were not normally distributed for ASD (S-W=0.015, 0.017 and 0.041 respectively). Data for all other variables were distributed normally. As the three main variables (total mean, dominant mean and nondominant mean) were normally distributed in both groups, a parametric analysis is most appropriate for the analysis of the role of IQ. As the majority of the data for the comparison pairs is normally distributed for both groups, parametric analysis will be conducted to assess the effect of comparison pair between groups for both hands.

Is IQ making a significant contribution to variance?

Mean *RT*s for the dominant and nondominant hand were entered into a 2*2 repeated measures ANCOVA, with hand as a within-subjects factor and group as a between-subjects factor. IQ Standard Score was entered as the covariate.

The sphericity assumption was violated; therefore the following values are Greenhouse-Geisser adjustments.

Hand used had a significant effect on RT, with the dominant hand being significantly slower than the nondominant hand: $F(1,20) = 7.36, p < 0.05, P = 0.733$, mean difference=45.812 (SE=22.834).

There was a Hand*IQ interaction: $F(1,20) = 5.592, p < 0.05, P = 0.641$. Hand*group was not significant, although observed power was considerably less ($P = 0.125$).

The covariate had no significant main effect on RT, although as indicated by the significant interaction with hand, IQ made a significant contribution to variance for the dominant hand: $b = -6.076, t = -2.448, p = 0.024$. For this reason data for the dominant hand should be analysed with a covariate included, while the nondominant data should be analysed without IQ as a covariate, to conserve power. However, as power for the dominant hand was markedly higher than that for the nondominant hand ($P = 0.644$ and 0.123 respectively), an ANCOVA will also be performed with data from the nondominant hand and any differences between this and the ANOVA will be detailed.

Final analysis

Dominant hand ANCOVA

Means for the dominant hand were entered into a 3*2 repeated measures ANCOVA, with comparison pair as a within-subjects variable, group as the between-subjects factor and IQ Standard Score as the covariate.

Means and standard deviations for both groups for the three comparison pairs are shown in Table 10 below.

Comparison pair	Group (n)	Mean RT (2dp) (ms)	Standard Deviation
Medium vs. large	ASD(10)	870.66	320.89
Medium vs. large	TD(12)	751.63	220.70
Small vs. large	ASD(10)	728.33	202.55
Small vs. large	TD(12)	692.35	138.92
Small vs. medium	ASD(10)	899.97	286.22
Small vs. medium	TD(12)	792.06	169.88

Table 10: Mean RT and Standard Deviation for each group for the three comparison pairs

There was no effect of comparison pair, however power was very low (<0.1).

Two of the three comparison pairs passed the Levene's Test, with small vs. medium failing, suggesting that for this condition RT variance was not equal for the two groups. As 1/3 of the variables failed Levene's, nonparametric analysis of the three comparison pairs was performed and this verified that comparison pair did not significantly affect RTs between groups.

There was a significant main effect of IQ: $F(1, 19) = 4.44, p < 0.05, P = 0.516$. Group was found to have no significant effect on RT, although observed power was lower than that observed for IQ ($P = 0.140$).

Parameter estimates highlight a larger contribution of IQ to variance in the easiest comparison (small vs. large), although this fell just short of significance. Each comparison pair had varying observed power, so it is difficult to draw any conclusions from the parameter estimates. Pairwise comparisons showed RTs for the two comparison pairs containing the large tiger were significantly different, with responses to small vs. large being faster than those to medium vs. large: mean difference=100.443 (SE=29.897), $p < 0.05$. Mean RTs for both groups for each comparison pair are shown in Figure 11 below.

As comparison pair was found to be non-significant, the ANCOVA was rerun as a univariate analysis with Standard Score as a covariate and using total dominant means (collapsing comparison pair) as a dependent variable. This was done in order to see if this theoretical increase in power showed a significant effect of group (the fixed factor). Power was still low and there was still no significant effect of group on RTs, with IQ still having a significant effect on mean RT.

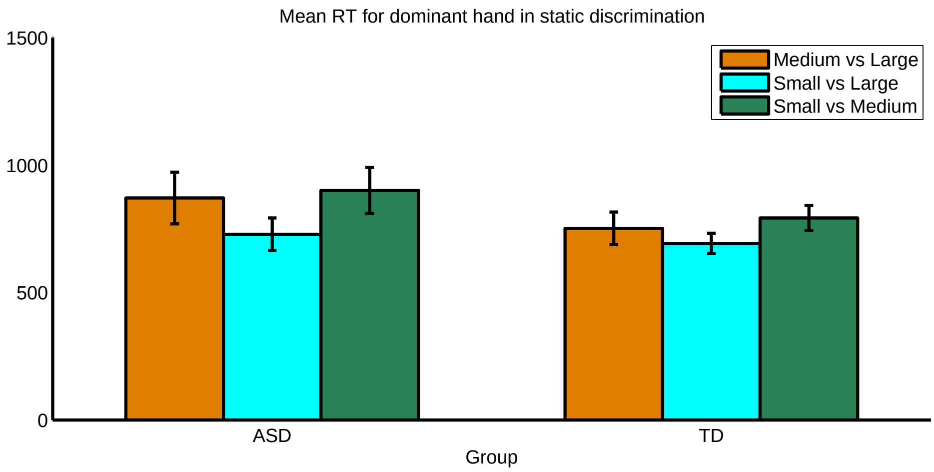

Figure 11: Mean RT for the dominant hand in static discrimination

Nondominant ANCOVA

Although IQ was found to not be significant in the initial ANCOVA assessing the contribution of hand and IQ, as power was very low an analysis of covariance will be performed and then compared to an ANOVA, which was initially deemed most appropriate.

Data was entered into analysis as described above. Means and standard deviations are given in Table 11 below.

Although power was slightly higher than for the dominant hand ($P = 0.314$), comparison pair was still not significant. There was no significant effect of group (controlling for

Comparison pair	Group (n)	Mean RT (2dp) (ms)	Standard Deviation
Medium vs. large	ASD(11)	784.40	228.30
Medium vs. large	TD(12)	691.65	142.58
Small vs. large	ASD(11)	736.73	225.22
Small vs. large	TD(12)	652.59	141.10
Small vs. medium	ASD(11)	905.76	257.71
Small vs. medium	TD(12)	734.93	171.29

Table 11: Mean RT and Standard Deviation for each group for the three comparison pairs using the nondominant hand

IQ) or IQ itself ($p = 0.196, P = 0.247$ and $p = 0.427, P = 0.121$).

Pairwise comparisons show that again, small vs. large was responded to significantly faster than small vs. medium: $p < 0.001$. Mean RTs for the two conditions containing the medium tiger showed a trend toward becoming significantly different: $p = 0.072$. See Figure 12.

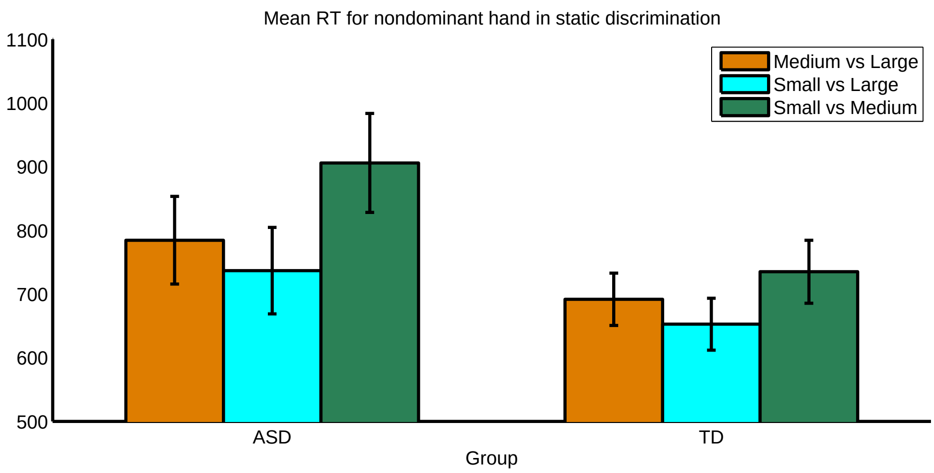

Figure 12: Mean RT for the nondominant hand in static discrimination

As with the dominant hand, as comparison pair was not significant, coupled with a nonsignificant effect of group (with low power), a univariate analysis was conducted with nondominant mean as the dependent variable, group as the fixed factor and IQ as the covariate.

Although power was increased slightly, it was still <0.3 and there was no significant effect of group. The same is true for IQ.

Nondominant ANOVA

Finally, data for the nondominant hand was entered into a 3*2 ANOVA, as preliminary analysis outlined above found IQ as a covariate to make no significant contribution to variance in RTs.

Means and standard deviations for the two groups across the three comparison pairs are the same as those shown in Table 10.

Unlike the ANCOVA detailed previously, comparison pair is found to be significant: $F(2,42) = 7.544, p < 0.05, P = 0.929$.

Again, there was no main effect of group ($p = 0.128, P = 0.327$), with the mean difference being 115.904 (SE=73.194).

As was seen in the ANCOVA above, there was a significant difference in *RT*s for the two comparison pairs containing a small tiger, mean difference=125.682 (SE=26251), $p < 0.001$, with Small vs. Large producing shorter *RT*s than Small vs. Medium. This follows a similar pattern to the dominant hand, in which the comparison pair comprising the two most disparate sizes produces shorter *RT*s than the others.

Static discrimination summary
IQ had a significant effect on *RT*s when subjects responded with the dominant hand. Small vs. large and small vs. medium elicited significantly different mean *RT*s when subjects responded with the nondominant hand, with small vs. large being responded to significantly faster than the more difficult comparison pair. Small vs. large and medium vs. large elicited significantly different *RT*s when responses were made with the dominant hand. As with the dominant hand, *RT*s were longer for the more difficult of the two comparison pairs. Mean *RT*s did not differ across groups for either hand.

Dynamic conditions

Single dynamic change detection: detecting acceleration in a single laterally presented looming target

- Video (L224, L234, L332, L334, R222, R232, R322, R324)[2]
- Within each video there were three variables:
  a (0.002, 0.003), *accstart* (0.2, 0.3) and u (0.2, 0.4)
- Hand used (dominant, nondominant)

Single dynamic change detection accuracy

Responses were deemed accurate if they were made after the point of acceleration and before the end of the trial. The accuracy rate for the ASD group was 76% and the accuracy rate for the TD group was 96%. Accuracy was entered as the dependent variable in a univariate ANOVA, with group as the fixed factor and IQ standard score as a covariate.

[2] R324 indicates that the target was on the right, a=0.003, *accstart*=0.2 and u=0.4. L denotes a target on the left.

Both group and IQ had a significant effect on accuracy rates: $F(1,573) = 35.242$, $p < 0.001$ and $F(1,573) = 16.658$, $p < 0.001$ respectively.

Single dynamic change detection *RT*

Normality

Dependent variables listed in Table 12 were analysed for normality of distribution for both groups.

Dependent variable	Distribution (p-value from Shapiro-Wilks test)
Overall mean RT	Normal
Overall mean RT for dominant hand	Normal
Overall mean RT for nondominant hand	Normal
Mean RT when $u = 0.2$ for the dominant hand	Normal
Mean RT when $u = 0.2$ for the nondominant hand	Not normally distributed for ASD ($p = 0.049$)
Mean RT when $u = 0.4$ for the dominant hand	Normal
Mean RT when $u = 0.4$ for the nondominant hand	Normal
Mean RT when $a = 0.002$ for the dominant hand	Normal
Mean RT when $a = 0.002$ for the nondominant hand	Not normally distributed for TD ($p = 0.007$)
Mean RT when $a = 0.003$ for the dominant hand	Normal
Mean RT when $a = 0.003$ for the nondominant hand	Normal
Mean RT when $accstart = 0.2$ for the dominant hand	Normal
Mean RT when $accstart = 0.2$ for the nondominant hand	Normal
Mean RT when $accstart = 0.3$ for the dominant hand	Normal
Mean RT when $accstart = 0.3$ for the nondominant hand	Normal

Table 12: Results from test of normality for single dynamic change detection variables

As the three main variables are normally distributed for both groups, subsequent preliminary analysis of the effect of IQ will be parametric. As the majority of task-specific variables were normally distributed, analysis of a, u and $accstart$ will be parametric.

Is IQ making a significant contribution to variance?

Data was entered into a 2*2 repeated measures ANCOVA with hand used (dominant, nondominant) as a within-subjects factor, group (ASD, TD) as a between-subjects factor and IQ Standard Score as a covariate. It was found that IQ fell just outside the critical alpha level: $p = 0.054$. This was with moderate power so for this reason final analysis will use an ANCOVA, as it seems quite possible that IQ would have been a significant factor if statistical power were marginally higher. An ANOVA will also be performed and any differences arising from reduced power in the ANCOVA will be reported.

Hand used had no significant effect on RT, although the dominant hand tended to be slower (mean difference=208.772 (SE=225.964)). Although hand used was not a significant contributor to differences in RT, analysis will still be split by hand to allow for comparisons across conditions according to hand used.

Final analysis

Analysis for the two dynamic conditions will be spilt into six separate analyses: u (dominant and nondominant), *accstart* (dominant and nondominant) and a (dominant and nondominant).

Dominant u (initial speed)

Subject means were entered into a 2*2 repeated measures ANCOVA, with u (0.2, 0.4) as a within-subjects factor, group (ASD, TD) as a between-subjects factor and IQ Standard Score as the covariate. Means and standard deviations for the two values of u for both groups are given in Table 13.

u	Group(n)	Mean RT (ms)	Standard deviation
0.2	ASD(11)	3627.82	1532.44
0.2	TD(11)	3756.65	597.66
0.4	ASD(11)	2634.42	1161.31
0.4	TD(11)	2086.52	443.76

Table 13: Mean RT and Standard deviation for both values of u for both groups

The sphericity assumption was not met therefore the following values are Greenhouse-Geisser adjustments.

Task variable (u) There was a significant effect of initial speed: $F(1, 19) = 9.358$, $p < 0.05$, $P = 0.827$. Mean difference between the two values of u was 1331.759, with $u = 0.4$ (the faster of the two initial speeds) eliciting faster responses than when $u = 0.2$. See Figure 13. u did not interact significantly with IQ but did with group: $F(1, 19) = 8.372, p < 0.05, P = 0.784$.

IQ and group

IQ was found to have a significant effect on RTs: $F(1, 19) = 6.078, p < 0.05, P = 0.648$. After controlling for the effect of IQ, group did not make a significant difference to RTs, although power was drastically lower ($P = 0.052$) than that observed for IQ.

Nondominant u

Data was entered into analysis as described above for dominant hand. Means and standard deviations for both values of u for both groups are shown in Table 14 below.

Task variable (u)

Again, there is a significant effect of initial speed of the target: $F(1, 19) = 6.760, p < 0.05, P = 0.694$ (Greenhouse-Geisser). Mean difference was greater than that for the

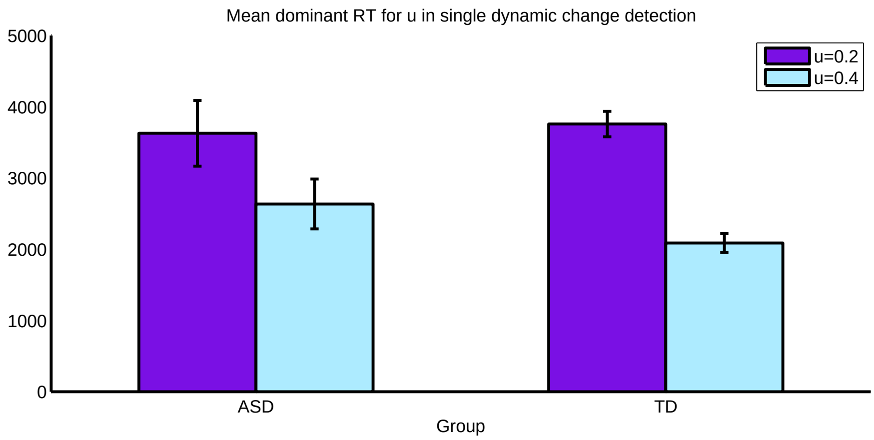

Figure 13: Mean RT for the dominant hand for both values of u in single dynamic change detection

u	Group(n)	Mean RT (ms)	Standard deviation
0.2	ASD(11)	3928	1781.67
0.2	TD(11)	3848.42	678.77
0.4	ASD(11)	2404.46	865.59
0.4	TD(11)	2078.42	464.71

Table 14: Mean RT and Standard deviation for both values of u for both groups

dominant hand but followed the same pattern, with $u = 0.4$ eliciting faster response than $u = 0.2$: mean difference=1646.773 (SE=174.215). u did not significantly interact with either group or IQ, although observed power was considerably less ($P = 0.16$ and $P = 0.282$ respectively).

IQ and group

Unsurprisingly, due to the nonsignificant interactions, neither group (controlling for IQ), nor the covariate itself, was a significant main effect, although, again, power did not exceed 0.162. The mean difference between groups was only 106.814 (SE=430.957), with TD being faster but not significantly so.

As the effect of IQ was found to fall just short of significance in the preliminary analysis of the effect of IQ, the covariate analysis detailed above will now be compared to analysis without a covariate.

Dominant u (ANOVA)

Data was entered into a 2*2 repeated measures ANOVA. Assumptions of sphericity were not met; therefore the following values are Greenhouse-Geisser adjustments.

As with the ANCOVA, there was a significant effect of u: $F(1, 20) = 93.169, p < 0.001$. There was also a significant u*group interaction: $F(1, 20) = 6.014, p < 0.05$. Group was not significant. As this was also true in the original ANCOVA, it is assumed that the significant u*group interaction is an expression of the significant effect of IQ found in the

ANCOVA detailed above, as the ASD group had a lower mean IQ than the TD group. Mean and standard deviations for both values of u for each group are are the same as those given in Table 12.

Nondominant u (ANOVA)

Again, data was entered into a 2*2 repeated measures ANOVA and again, sphericity assumption was violated. As was the case in the ANCOVA, there was a significant effect of u on mean RT: $F(1, 20) = 84.629, p < 0.001$. There was no interaction of u and group, in line with the non-significant interaction of u and IQ in the covariate analysis detailed previously. Again, developmental group did not significantly affect mean RT when considering varying values of initial speed.

u summary
There was a significant effect of initial speed for both hands, with $u = 0.4$ eliciting faster responses than $u = 0.2$.
IQ was found to interact significantly with u in the dominant hand and was also a significant between-subjects effect for the dominant hand. IQ did not significantly affect RT when responses were produced by the nondominant hand.
RTs produced by each group were statistically comparable, with no group effect for either hand, whilst controlling for IQ.
A repeated measures ANOVA comparing u and group verified the significant effect of u for both hands. The analysis also highlighted a significant interaction effect between u and group: $F(1, 20) = 6.014, p < 0.05, P = 0.646$ (again, Greenhouse-Geisser adjusted value). As the IQ of the two groups was not equal, and no longer held equal by the use of a covariate, this interaction is likely a different expression of the u*IQ interaction found initially.

Dominant a (acceleration)

Subject means were entered into a 2*2 repeated measures ANCOVA, with a (0.002, 0.003) as a within-subjects factor, group (ASD, TD) as a between-subjects factor and IQ Standard Score as the covariate. Means and standard deviations for the two values of a for both groups are shown below in Table 15.

Task variable (a)

There was no significant effect of acceleration rate and no interaction with IQ although an interaction with group was close to significance with moderate power: $p = 0.06, P = 0.475$. (Greenhouse-Geisser).

IQ and group

a	Group(n)	Mean RT (ms)	Standard deviation
0.002	ASD(12)	3133.52	1608.63
0.002	TD(11)	3562.52	1022.67
0.003	ASD(12)	3168.76	1372.33
0.003	TD(11)	2855.89	408.00

Table 15: Mean RT and Standard deviation for both values of a for both groups using the dominant hand

The covariate (IQ Standard Score) was significantly related to RT: $F(1,20) = 7.1$, $p < 0.05, P = 0.717$. There was no significant main effect of group, when IQ was controlled for, although power was less than 0.2 and due to the trend toward a significant interaction involving group, it is possible that increased power could give a significant effect of group, particularly when considered against the nonsignificant effect of a, with which group has a close-to-significant interaction.

Nondominant a

Data from the nondominant hand was entered into analysis as described above.

Means and standard deviations for the two groups across the two values of a are given in Table 16.

a	Group(n)	Mean RT (ms)	Standard deviation
0.002	ASD(12)	3017.84	1485.39
0.002	TD(11)	2776.63	1114.22
0.003	ASD(12)	3246.88	1489.64
0.003	TD(11)	2832.59	526.75

Table 16: Mean RT and Standard deviation for both values of a for both groups using the nondominant hand

As with the dominant hand, there was no effect of acceleration rate and no interactions with either IQ or group, although in all cases $P < 0.2$.

There was no significant main effect of group, when IQ was controlled for, or of IQ itself, although again power was < 0.2.

Again, as the effect of IQ was found to fall just short of significance in the preliminary analysis of the effect of IQ, the covariate analysis detailed above will now be compared to analysis without a covariate.

Dominant a (ANOVA)

As with the covariate analysis, there was no effect of acceleration rate on RT, nor was there a significant effect of group.

Nondominant a (ANOVA)

Again, as with the covariate analysis detailed above, acceleration rate made no significant difference to mean RT for the nondominant hand. This is also true for group.

> **a summary**
> There was no effect of varying the value of a (acceleration) in either hand. There was a significant effect of IQ only in the dominant hand. Group was non-significant for both hands, although power was low. Without controlling for IQ, group remained non-significant, although again power was still < 0.2. A repeated measures ANOVA comparing a and group verified that varying acceleration rate had no significant effect on RT, and there was no significant effect of group on mean RT. a*group showed a trend toward significance ($p = 0.079$) in the dominant hand, which is likely to be an expression of the significant a*IQ interaction originally found.

Dominant *accstart* (fraction of video duration after which the tiger accelerated)

Subject means were entered into a repeated measures ANCOVA, with *accstart* (0.2, 0.3) as a within-subjects variable, group as a between-subjects variable and IQ as the covariate. Means and standard deviations for the two values of *accstart* are given for each group in Table 17.

accstart	Group(n)	Mean RT (ms)	Standard deviation
0.2	ASD(10)	2939.40	1066.41
0.2	TD(11)	3007.92	782.74
0.3	ASD(10)	3067.04	1258.05
0.3	TD(11)	3649.33	862.64

Table 17: Mean RT and Standard deviation for both values of *accstart* for both groups using the dominant hand

There were no significant effects of *accstart*, group, or IQ, although power never exceeded 0.319 so it is possible that some significant effects are missed. Pairwise comparison shows that the RTs elicited by the two values of accstart are close to being significantly different: mean difference=382.804 (*accstart*=0.2 is responded to faster, $SE = 183.144, p = 0.051$). These differences are illustrated in Figure 14

.

Nondominant accstart

Data for the nondominant hand was entered into analysis as described above.

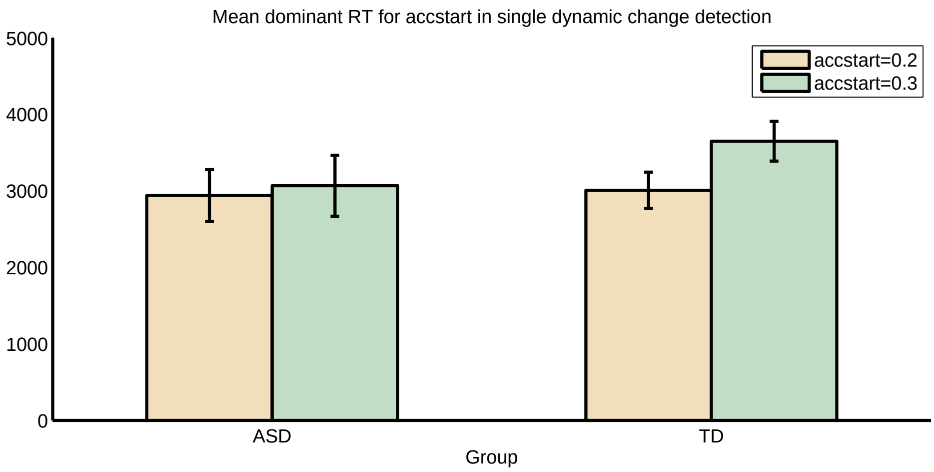

Figure 14: Mean *RT* for the dominant hand for both values of *accstart* in single dynamic change detection

Means and standard deviations for the two values of accstart for both groups are described in Table 18 below.

accstart	Group(n)	Mean RT (ms)	Standard deviation
0.2	ASD(12)	3070.13	1284.97
0.2	TD(11)	2806.78	629.93
0.3	ASD(12)	3334.65	1661.78
0.3	TD(11)	2919.60	915.14

Table 18: Mean *RT* and Standard deviation for both values of *accstart* for both groups using the nondominant hand

Again there are no significant effects of *accstart*, group or IQ, although power is still relatively low.

Once again, as covariate analysis was prompted only by a near-significant effect of IQ in preliminary IQ analysis, analysis of variance without a covariate will now be detailed.

Dominant *accstart* (ANOVA)

Data was entered into a 2*2 repeated measures ANOVA. In this instance, without the covariate, there was a significant effect of *accstart*: $F(1,19) = 4.395, p = 0.05, P = 0.512$. As was the case in the covariate analysis, there was no effect of group on mean RT.

Nondominant *accstart* (ANOVA)

Data was entered into a 2*2 repeated measures ANOVA. As was the case in the covariate analysis of data from the nondominant hand, there was no effect of accstart or group on mean RT.

***accstart* summary**

Covariate analysis highlighted a trend toward a significant difference between *RT*s elicited by the two values of *accstart* for the dominant hand, although power was relatively low. Neither group nor IQ significantly affected *RT*s for either hand, but again, power was low.

A repeated measures ANOVA comparing *accstart* and group found the trend toward significance for *accstart* expressed as a significant effect for the dominant hand: $F(1,19) = 4.395, p = 0.05, P = 0.512$ (Greenhouse-Geisser). Mean difference between the two values was 384.53 (SE=183.415), with quicker responses recorded when $accstart = 0.2$. Even with the increased in power by excluding the covariate, group and interactions with group remained a nonsignificant contributor to variance in *RT* for both hands.

Total mean univariate analysis with covariate

A univariate analysis with IQ as a covariate was conducted to assess any differences between the two groups when considering all variables (a, u, *accstart*) together.

Dominant

Means for the dominant hand were entered into univariate analysis as the dependent variable, with group as the fixed factor and IQ as the covariate.

Means and standard deviations are shown in Table 19 below.

Group(n)	Mean RT (ms)	Standard deviation
ASD(12)	3128.22	1297.46
TD(11)	3193.27	643.30

Table 19: Mean *RT* and Standard deviation for both groups using the dominant hand

There was a significant effect of IQ, but no effect of group once IQ was factored in: $F(1,20) = 6.643, p < 0.05, P = 0.689$ and $F(1,20) = 0.837, p = 0.371, P = 0.141$ respectively.

Nondominant

Means for the nondominant hand were entered into analysis as descried above. Means and standard deviations are given in Table 20.

Neither IQ nor group was significant although in both cases $P < 0.16$.

Group(n)	Mean RT (ms)	Standard deviation
ASD(12)	3103.02	1309.36
TD(11)	2808.17	728.10

Table 20: Mean RT and Standard deviation for both groups using the nondominant hand

Single dynamic change detection summary
Varying values of u and $accstart$ had a significant effect on mean RT: changing the value of u affected both hands, while changing the value of $accstart$ only had a significant effect on RTs when responses were made with the dominant hand. When looking at the condition as a whole (without partitioning out different variables) IQ significantly affected RTs produced by the dominant hand. There was no overall effect of developmental group and no group effect for any specific variable that was manipulated throughout the trials.

Dynamic discrimination: stop the faster tiger

- Video (L224, L234, L332, L334, R222, R232, R322, R324)
- Within each video there were three variables:
  a (0.002, 0.003), $accstart$ (0.2, 0.3) and u (0.2, 0.4)
- Hand used (dominant, nondominant)

Dynamic discrimination accuracy

Accurate responses are defined as those which were both a) the correct button press and b) after the point of acceleration (meaning that negative $RT_{relative}$ were discounted). One participant from the ASD group was excluded from accuracy analysis as his performance was not deemed to be representative of the ASD group as a whole. Excluding this participant, the ASD group gave an accurate response in 93% of the trials, while the TD group gave accurate responses for 95% of the trials. Univariate analysis revealed this difference to be not-significant.

Normality

Dependent variables listed in Table 21 were analysed for normality of distribution for both groups. All data was normally distributed therefore parametric tests (either repeated measures ANCOVA or ANOVA) are appropriate for further analysis.

Is IQ making a significant contribution to variance?

Subjects' overall means for the dominant and nondominant hand were entered into a 2*2 repeated measures ANCOVA, with hand as a within-subjects factor, group as a between-

Dependent variable
Overall mean RT
Overall mean RT for dominant hand
Overall mean RT for nondominant hand
Mean RT when u=0.2 for the dominant hand
Mean RT when u=0.2 for the nondominant hand
Mean RT when u=0.4 for the dominant hand
Mean RT when u=0.4 for the nondominant hand
Mean RT when a=0.002 for the dominant hand
Mean RT when a=0.002 for the nondominant hand
Mean RT when a=0.003 for the dominant hand
Mean RT when a=0.003 for the nondominant hand
Mean RT when $accstart$=0.2 for the dominant hand
Mean RT when $accstart$=0.2 for the nondominant hand
Mean RT when $accstart$=0.3 for the dominant hand
Mean RT when $accstart$=0.3 for the nondominant hand

Table 21: Dependent variables for dynamic discrimination

subjects factor and IQ Standard Score as a covariate.

Hand used had a significant effect on RT: $F(1, 21) = 4.738, p < 0.05, P = 0.546$. The dominant hand produced significantly slower RTs than the nondominant hand, with a mean difference of 829.25 (SE=459.265). IQ had no significant effect on RT. Despite low power, these findings suggest that final analysis should not include IQ as a covariate. To confirm this, a univariate ANCOVA was performed with overall mean RT as the dependent variable, group as the fixed factor and IQ as the covariate. This also found no significant contribution of IQ to the variance across the two groups. As both tests found no significant effect of IQ, the final analysis of the dynamic discrimination task will not include IQ as a covariate.

Final analysis

Dominant u

Subject means for the two values of initial speed were entered into a 2*2 repeated measures ANOVA, with u as a within-subjects factor and group as a between-subjects factor.

Means and standard deviations for the two values of u for both groups are shown in Table 22.

u	Group(n)	Mean RT (ms)	Standard deviation
0.2	ASD(12)	5751.48	1213.95
0.2	TD(12)	4896.95	877.45
0.4	ASD(12)	4954.50	1411.70
0.4	TD(12)	3550.94	812.24

Table 22: The mean RT and Standard deviation for both groups using the dominant hand

Task variable (u)

There was a highly significant effect of u, with perfect power, with RTs in trials in which $u = 0.4$ being significantly faster than those when $u = 0.2$: $F(1,22) = 61.61$, $p < 0.001, P = 1$, mean difference=1075.998 (SE=137.083). An interaction of u*group was close to significance with moderate power: $F(1,22) = 3.88, p = 0.062, P = 0.47$. Both values cited are Greenhouse-Geisser adjusted values as the sphericity assumption is violated.

Group

Mean RTs for the two groups were found to be significantly different: $F(1,22) = 6.828, p < 0.05, P = 0.705$. Mean difference is 1124.543 (SE=430.369), with TD responding faster than ASD subjects. Both the effect of u and group are shown in Figure 15

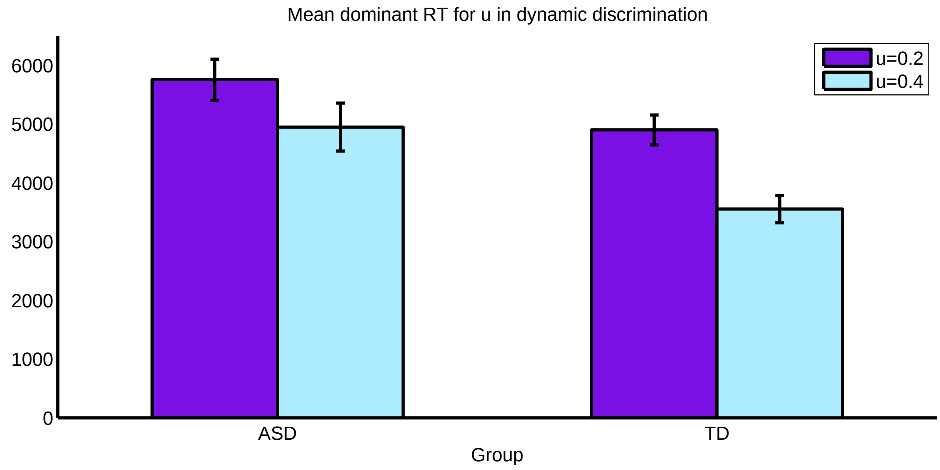

Figure 15: Mean RT for the dominant hand for both values of u in dynamic discrimination

Nondominant u

Data for the nondominant hand was entered into analysis as described above.

Again, means and standard deviations for the two values of u are given in Table 23 below.

u	Group(n)	Mean RT (ms)	Standard deviation
0.2	ASD(12)	5413.33	1365.43
0.2	TD(12)	4582.04	791.45
0.4	ASD(12)	4311.61	1506.55
0.4	TD(12)	3621.98	822.92

Table 23: The mean RT and Standard deviation for both groups using the nondominant hand

Task variable (u)

As seen in the dominant hand, the two values of initial speed elicit significantly different RTs: $F(1,22) = 53.599, p < 0.001, P = 1$ (Greenhouse-Geisser). As with the dominant hand, responses when u=0.4 were faster than when u=0.2: Mean difference=1030.891 (SE=140.811). Again, there was no interaction between u and group: it appears that u has a similar effect in both groups, as can be seen in Figure 16.

Group

Unlike the dominant hand, there was no significant main effect of group: $F(1, 22) = 2.797, p = 0.109, P = 0.359$.

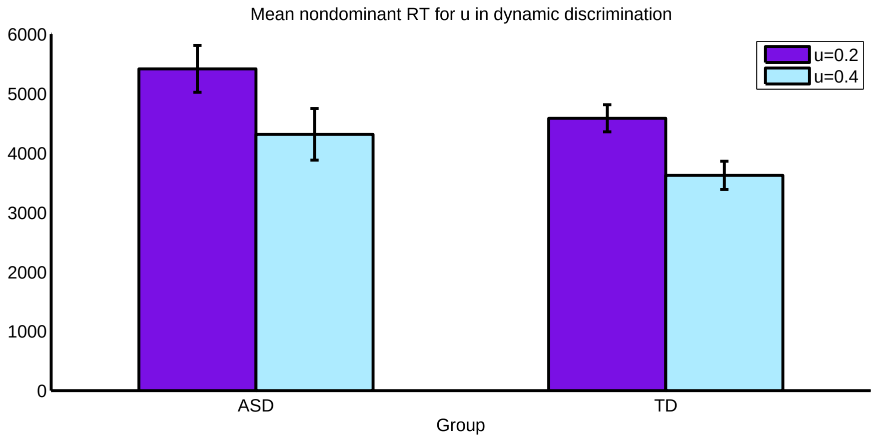

Figure 16: Mean RT for the nondominant hand for both values of u in dynamic discrimination

u summary

Varying the value of u had a significant effect on RTs produced by both hands, with responses in trials where u=0.4 being significantly faster than when u=0.2. The group to which subjects belonged only had a significant effect on their mean RTs for the dominant hand, with the two groups performing comparably with the nondominant hand.

Dominant a

Data was entered into a 2*2 repeated measures ANOVA with a as a within-subjects factor and group as a between-subjects factor.

Means and standard deviations for the two values of a for both groups are given in Table 24.

a	Group(n)	Mean RT (ms)	Standard deviation
0.002	ASD(12)	5780.12	1249.72
0.002	TD(12)	4813.39	1176.14
0.003	ASD(12)	5266.78	1266.83
0.003	TD(12)	4115.24	784.76

Table 24: The mean RT and Standard deviation for both groups using the dominant hand

Task variable (a)

There was a significant within-subjects effect of a: $F(1,22) = 14.872, p < 0.001$, $P = 0.958$. (Greenhouse-Geisser).

Group

There was also a significant main effect of group, with the control group responding significantly faster than the ASD group: $F(1,22) = 5.886, p < 0.05$, $P = 0.64$, mean difference=1059.134 (SE=436.54).

These effects are shown in Figure 17 below.

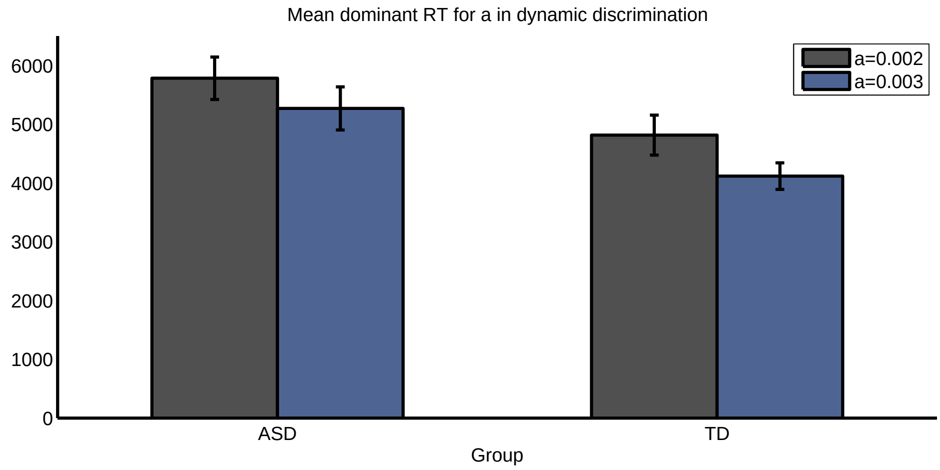

Figure 17: Mean RT for the dominant hand for both values of a in dynamic discrimination

Nondominant a

Data for the nondominant hand was entered into analysis as described above. Means and standard deviations for the within-subjects variable for each group are detailed in Table 25 below.

a	Group(n)	Mean RT (ms)	Standard deviation
0.002	ASD(12)	4823.70	1726.92
0.002	TD(12)	4056.94	649.66
0.003	ASD(12)	4721.71	1459.45
0.003	TD(12)	4026.09	736.58

Table 25: The mean RT and Standard deviation for both groups using the nondominant hand

Task variable (a)

There was no significant within-subjects effect of a, which was present in the dominant hand, although power was < 0.1.

One of the two variables entered into analysis failed Levene's Test of Homoscedasticity, therefore a nonparametric analysis of this condition was also conducted. This analysis did not report findings disparate from those from the parametric analysis.

Group

Unlike the dominant hand, there was no significant effect of group, however observed power was less in this instance: $F(1,22) = 2.285, p = 0.145, P = 0.304$. Mean difference was 731.189 (SE=483.701), with TD being faster, although not significantly so. Parameter estimates show group to make no significant contribution to variance of *RT* for either value of *a*.

> ***a* summary**
> There was a significant effect of *a* on reaction time for the dominant hand, although this finding was not replicated for the nondominant hand, however in the latter case, observed power was <0.1. Group had a significant effect on *RT* only for responses made with the dominant hand.

Dominant accstart

Subject means were entered into a 2*2 repeated measures ANOVA, with *accstart* as a within-subjects factor and group as the between-subjects factor. Means and standard deviations are shown in Table 26.

accstart	Group(n)	Mean RT (ms)	Standard deviation
0.2	ASD(12)	5547.83	1287.78
0.2	TD(12)	4315.17	986.38
0.3	ASD(12)	5397.50	1317.16
0.3	TD(12)	5121.29	1064.18

Table 26: The mean *RT* and Standard deviation for both groups using the dominant hand

Task variable (*accstart*)

There was no significant effect of varying *accstart* or an interaction with *accstart* and group, although power was low (0.142 and 0.35 respectively).

Group

Group was very close to being a significant main effect of *RT* variance, and would likely become significant if power was increased by including more subjects: $F(1,22) = 4.273, p = 0.051, P = 0.507$. Mean difference was 892.538 (SE=431.79), with TD subjects responding faster than ASD. See Figure 18.

Nondominant accstart

Data for the nondominant hand was entered into analysis as described above. Means and standard deviations for the two values of *accstart* for both groups are given in Table 27 below.

Task variable (*accstart*)

Again, there was no effect of *accstart*. However, one of the two variables did not pass Levene's Test, therefore a nonparametric analysis was carried out to investigate the effect of *accstart* for the nondominant hand.

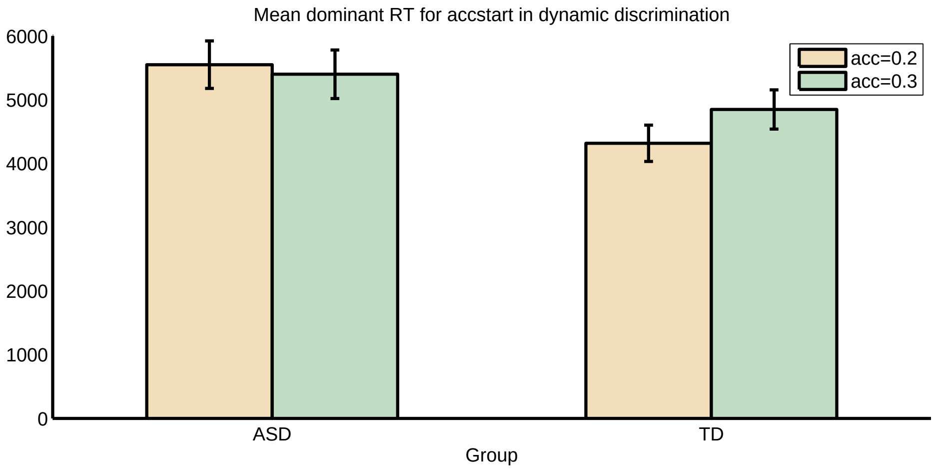

Figure 18: Mean *RT* for the dominant hand for both values of *accstart* in dynamic discrimination

accstart	Group(n)	Mean RT (ms)	Standard deviation
0.2	ASD(12)	4712.50	1792.26
0.2	TD(12)	3876.91	714.62
0.3	ASD(12)	4913.70	1683.01
0.3	TD(12)	4209.96	577.01

Table 27: The mean *RT* and Standard deviation for both groups using the nondominant hand

Data was entered into a Kruskal-Wallis test and this confirmed that there was no significant effect of *accstart* for the nondominant hand.

Group

There was no significant effect of group on mean *RT* using the nondominant hand.

***accstart* summary**

Varying *accstart* did not significantly affect mean *RT*s for either hand. Mean reaction times for the two groups were very close to being significantly different for the dominant hand, although not for the nondominant hand.

Univariate analysis of overall mean *RT*

Dominant

Overall mean *RT*s for the dominant hand were entered into univariate analysis as a dependent variable, with group as a fixed factor.

Means and standard deviations are shown in Table 28.

There was a significant overall effect of group: $F(1,22) = 5.798, p < 0.05, P = 0.634$. Mean difference was 1060.75 (SE=440.535), with ASD responding significantly slower.

Group(n)	Mean RT (ms)	Standard deviation
ASD(12)	5524.94	1216
TD(12)	4464.19	922.07

Table 28: Overall mean RT and Standard deviation for both groups using the dominant hand

Nondominant

Overall mean RTs for the nondominant hand were entered into analysis as described above. Means and standard deviations are given in Table 29.

Group(n)	Mean RT (ms)	Standard deviation
ASD(12)	4773.24	1555.5
TD(12)	4043.16	595.89

Table 29: Overall mean RT and Standard deviation for both groups using the nondominant hand

There was no significant overall effect of group when subjects responded using their non-preferred hand: $F(1,22) = 2.305, p = 0.143, P = 0.306$. Mean difference was 730.078 (SE=480.854).

Dynamic discrimination summary
Group significantly affected mean RT for the dominant hand. Varying the value of u significantly affect RT for both hands and varying the value of a had a significant effect on RTs produced by the dominant hand.

Dynamic conditions summary
Varying u and a had the same effect in both the dynamic change detection task and the dynamic discrimination task. When responding to a change in a single dynamic stimulus, IQ had a significant effect on RT, which was replaced with a group effect when a second stimulus was introduced and a between-objects discrimination was required.
In both tasks, the two hands appeared to respond differently, in both cases with the dominant hand lagging behind the nondominant.

Summary of all tasks

IQ effects

IQ had a significant effect on RT in two of the five conditions (static discrimination and single dynamic change detection), when subjects responded with their dominant hand. In all other cases, IQ made no significant contribution to variance in RT.

Hand effects

*RT*s produced by the two hands were significantly different in three of the five conditions: centre target detection, static discrimination and dynamic discrimination. In each case, the nondominant hand produced significantly faster responses than the dominant hand.

Group effects

Mean *RT*s produced by the two groups differed significantly in the centre target detection condition for both hands, the side detection condition using the nondominant hand and the dynamic discrimination condition using the dominant hand.

This summary is also shown in Table 30.

Effect	Hand	Centre	Side	Static discrimination	Single dynamic	Dynamic discrimination
IQ effect	Dominant			*	*	
IQ effect	Nondominant					
Group effect	Dominant	*				*
Group effect	Nondominant	*	*			
Hand effect		*		*		*

Table 30: Results summary

Comparing tasks

In order to investigate the relative performance of each group across the five tasks, a number of conditions were directly compared. Analysis was also conducted to assess the contribution of visuomotor delay, and whether results detailed above are best explained solely by a motor delay, or whether some other factor is also affecting the performance of the ASD group over and above their longer visuomotor times.

Centre vs. side

Did single-target location (central or towards the periphery) affect *RT*s for either group?

ASD

Dominant

A paired-samples t-test comparing total mean *RT*s for ASD subjects (n=11) for the dominant hand for centre and side conditions was performed. Means and standard deviations are given in Table 31.

Target location did not significantly affect *RT*s in simple detection tasks for the ASD group, when using their dominant hand: $t(10) = 0.721, p = 0.487$.

Condition	Mean RT (ms)	Standard deviation
Centre	399.37	130.01
Side	378.62	98.72

Table 31: Mean *RT* and Standard deviation for ASD in static detection tasks using the dominant hand

Mean reaction times for the centre detection task were slower although not significantly so. There was a positive correlation between the two detection tasks: $r(9) = 0.683$, $p < 0.05$.

Nondominant

Means for the nondominant hand were analysed as described above, this time with n=10. Mean and standard deviations are given in Table 32.

Condition	Mean RT (ms)	Standard deviation
Centre	343.81	61.35
Side	396.84	114.70

Table 32: Mean *RT* and Standard deviation for ASD in static detection tasks using the nondominant hand

Again, there was no significant difference between *RT*s for the two detection tasks.

Where centre tended to be slower (although not significantly so) than side with the dominant hand, the inverse is true for the nondominant hand (although again, this is not a significant effect).

Unlike the dominant hand, there was no significant correlation between *RT*s for the two static target detection tasks.

TD

Data for TD subjects was analysed as described above for both hands.

Dominant

As with the ASD subjects, there was no significant difference between detection response times when the target was placed centrally or to the side.

Conversely to what was found in the ASD group, side was slower, although again, not significantly so.

Means and standard deviations are reported in Table 33.

Condition	Mean RT (ms)	Standard deviation
Centre	304.02	25.83
Side	314.66	34.47

Table 33: Mean *RT* and Standard deviation for TD in static detection tasks using the dominant hand

Nondominant

Unlike the ASD group, there was a significant difference between *RT*s elicited by the two conditions, with responses in the side condition being significantly slower: $t(10) = -3.066, p = 0.012(2 - tailed)$. Means and standard deviations are given in Table 34 below.

Condition	Mean RT (ms)	Standard deviation
Centre	279.70	28.10
Side	305.56	23.60

Table 34: Mean *RT* and Standard deviation for TD in static detection tasks using the nondominant hand

Centre vs. side target detection summary
For the ASD group, the location of the target did not affect *RT*s produced by either hand. The TD group was not affected by target location when using their dominant hand, although when using the non-preferred hand, *RT*s in the side detection task were significantly slower than those in the centre detection task.

Static detection vs. static discrimination

Mean *RT*s for each hand for the side detection and static discrimination tasks were compared to investigate whether subjects took significantly longer to make a discrimination than they do to make a detection response. Note that the centre detection task was not compared, as the target was not positioned in one of the two locations used in the discrimination task.

ASD

Dominant

Mean *RT*s for the dominant hand for the side detection and static discrimination task were entered into a pairwise t-test. Means and standard deviations are detailed in Table 35.

Condition	Mean RT (ms)	Standard deviation
Side	378.62	98.73
Static discrimination	852.61	206.83

Table 35: Mean *RT* and Standard deviation for ASD in static side detection and static discrimination tasks using the dominant hand

There was a highly significant difference between *RT*s for the two tasks: $t(10) = -9.360, p < 0.001$. There was a moderate positive correlation between the mean *RT* for the two tasks, although this fell short of the critical alpha value: $r(9) = 0.595, p = 0.053$.

Nondominant

Data for the nondominant hand was entered into analysis as outlined above. Means and standard deviations are given in Table 36.

Condition	Mean RT (ms)	Standard deviation
Side	393.00	109.56
Static discrimination	812.37	212.05

Table 36: Mean *RT* and Standard deviation for ASD in static side detection and static discrimination tasks using the nondominant hand

Again, there was a significant difference between mean *RT* for the two tasks: $t(10) = -6.771, p < 0.001$, although there was no significant correlation.

TD

Dominant

Data from the TD group was entered into pairwise analysis as described above.

Means and standard deviations are given below in Table 37.

Condition	Mean RT (ms)	Standard deviation
Side	317.06	34.83
Static discrimination	746.12	167.22

Table 37: Mean *RT* and Standard deviation for TD in static side detection and static discrimination tasks using the dominant hand

As with the ASD group, there was a significant difference between *RT*s for the two tasks when using the dominant hand: $t(11) = -8.918, p < 0.001$. However, in this case there was no significant correlation between *RT*s for the two tasks.

Nondominant

Data for the nondominant hand was entered into a paired samples t-test and means and standard deviations are given in Table 38.

Condition	Mean RT (ms)	Standard deviation
Side	310.30	27.87
Static discrimination	693.57	131.41

Table 38: Mean *RT* and Standard deviation for TD in static side detection and static discrimination tasks using the nondominant hand

As with the dominant hand, there was a significant difference in *RT* for the two tasks: $t(11) = -10.091, p < 0.001$, although again, there was no significant correlation between the mean *RT*s for the two tasks.

Side detection vs. static discrimination summary
For both groups, RTs were significantly slower when required to discriminate between two targets as opposed to detecting a single target in the same locations.

Dynamic detection vs. dynamic discrimination

Dynamic change detection was compared with dynamic discrimination, to investigate whether the inclusion of a second target makes dynamic change detection more difficult (shown by a slower mean RT for the dynamic discrimination task).

ASD

Dominant

Data for the dominant hand from the two dynamic conditions was entered into a paired-samples t-test. Means and standard deviations are shown below in Table 39.

Condition	Mean RT (ms)	Standard deviation
Dynamic change detection	3128.22	1297.46
Dynamic discrimination	5524.94	1215.99

Table 39: Mean RT and Standard deviation for ASD in dynamic change detection and dynamic discrimination tasks using the dominant hand

There was a significant difference between mean RT for the two dynamic tasks: $t(11) = -6.041, p < 0.001$. There was a trend toward a positive correlation between RTs produced in the two tasks, although this did not reach significance.

Nondominant

Data for the nondominant hand was entered into a paired-samples t-test and means and standard deviations are shown in table 40.

Condition	Mean RT (ms)	Standard deviation
Dynamic change detection	3103.02	1309.36
Dynamic discrimination	4773.24	1555.49

Table 40: Mean RT and Standard deviation for ASD in dynamic change detection and dynamic discrimination tasks using the nondominant hand

Again there was a significant difference between RTs for the two tasks: $t(11) = -4.753$, $p < 0.001$. There was also a positive correlation between RTs for the two dynamic discriminations: $r(10) = 0.651$, $p < 0.05$.

TD

Dominant

Data from the TD group for the two dynamic conditions was entered into a paired samples t-test. Means and standard deviations are given below in Table 41.

Condition	Mean RT (ms)	Standard deviation
Dynamic change detection	3193.27	643.30
Dynamic discrimination	4390.92	929.71

Table 41: Mean RT and Standard deviation for TD in dynamic change detection and dynamic discrimination tasks using the dominant hand

There was a negative correlation between RTs for the two tasks, although this was not significant. There was a significant difference between the mean RTs: $t(10) = -3.471$, $p =< 0.05$.

Nondominant

Data for the nondominant hand was entered into a paired samples t-test and means and standard deviations are given in Table 42.

Condition	Mean RT (ms)	Standard deviation
Dynamic change detection	2808.17	728.10
Dynamic discrimination	3995.22	600.22

Table 42: Mean RT and Standard deviation for TD in dynamic change detection and dynamic discrimination tasks using the nondominant hand

Again, there was a negative correlation between the two tasks (the inverse of the direction of correlation seen in the ASD group), although again this was not significant, although it was closer to significance: $r(9) = -0.461, p = 0.154$.

Dynamic detection vs. dynamic discrimination summary

For both groups, with both the dominant and the nondominant hand, there was a significant difference between RTs produced during the two tasks. Although the task was essentially the same (identify the point at which the tiger begins to accelerate), the inclusion of a second tiger to attend to and monitor resulted in significantly slower RTs for both groups. Figure 19 shows the mean RT for each video in the single and double dynamic tasks. The pattern is clearer if data is shown in a line graph, although note that the x-axis is not a continuum, as is usually the case in line graphs. See Figure 20.

In the ASD group, there was a significant positive correlation between the two tasks for the nondominant hand and a similar relationship in the dominant hand, although the latter was not significant. The inverse was true in the TD group, with a trend toward a negative correlation between RTs for the two tasks, however neither of these reached significance.

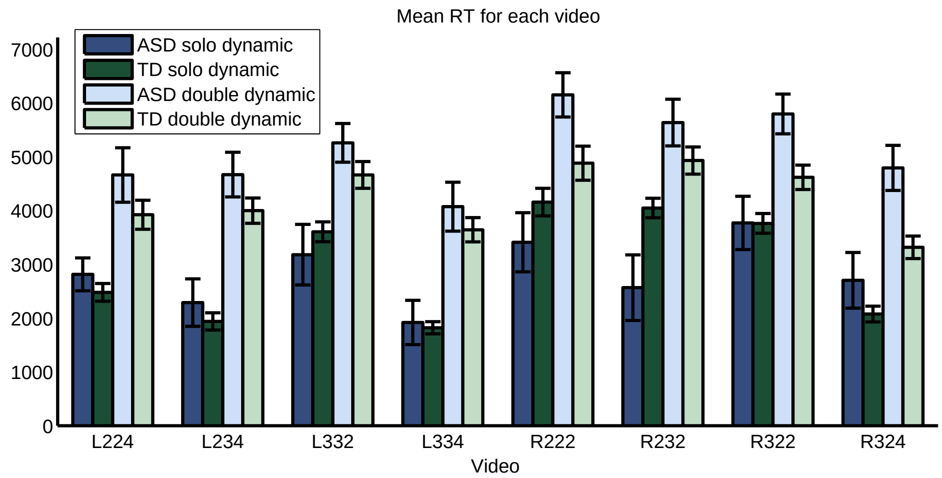

Figure 19: Mean RT for each video in both dynamic tasks

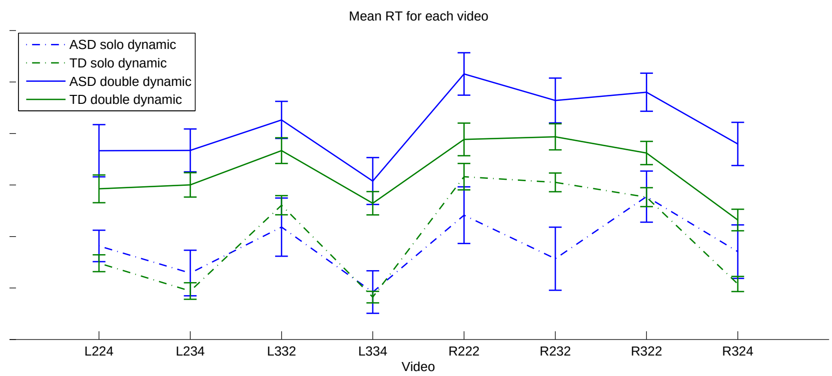

Figure 20: Mean RT for each video in both dynamic tasks. Note that the x-axis is not arranged as a continuum as is usual in line graphs.

Can a visuomotor delay explain the significant group effect in dynamic discrimination?

In order to investigate the role of visuomotor delays on the RTs recorded by the two groups, subjects' mean RTs for each condition were recalculated to removed visuomotor delay, so we are left with a cognitive RT: subjects' mean RT for the centre condition was subtracted from their mean for the dynamic discrimination condition. The remaining RT should be a truer reflection of his or her thinking and decision-making time, as the centre condition should in theory be a measure of each individual's visuomotor delay as there was no cognitive element to the task.

All ASD subjects were included in this further analysis, and 11 of the 12 TD subjects were included (one subject's mean RT for the centre condition had previously been deemed an outlier within his group).

As only the dominant hand showed a significant difference between the two groups, only that hand will be further analysed.

Adjusted means for the dynamic discrimination condition were entered into univariate analysis as a dependent variable, with group as the fixed factor and IQ Standard Score as the covariate. There was no effect of IQ and a significant difference between adjusted mean RTs for the two groups: $F(1, 20) = 4.556, p < 0.05, P = 0.529$. The dependent variable failed Levene's Test of homogeneity of variance, so a nonparametric test was conducted to ensure that the significant finding was accurate. The Kruskal-Wallis test confirmed that there was a significant difference between the two groups: $\chi^2(1, N = 23) = 4.91, p = 0.027$.

The significant group effect is shown in Figure 21.

This finding shows that neither IQ nor visuomotor delay accounts for the group difference in the dynamic discrimination task.

Final summary

Psychophysical variables

Task-specific independent variables (i.e. fixation duration, target size etc.) were altered in each task. These variables were included in order to have covered as wide a range of psychophysical properties as possible.

In the majority of cases, these variables had a similar effect in both groups. In static discrimination, both groups were faster to make a correct response to the easier comparison pair compared to one of the pairs in which the targets were of less disparate size. In dynamic conditions, initial speed of the target(s) (u) had a significant effect on RT for both groups, with the task (change detection or detection of the faster tiger) being comparatively easier when the tiger had been moving faster at the start of the trial. A faster initial speed is analogous with a relatively larger size at the point of acceleration compared to the slower

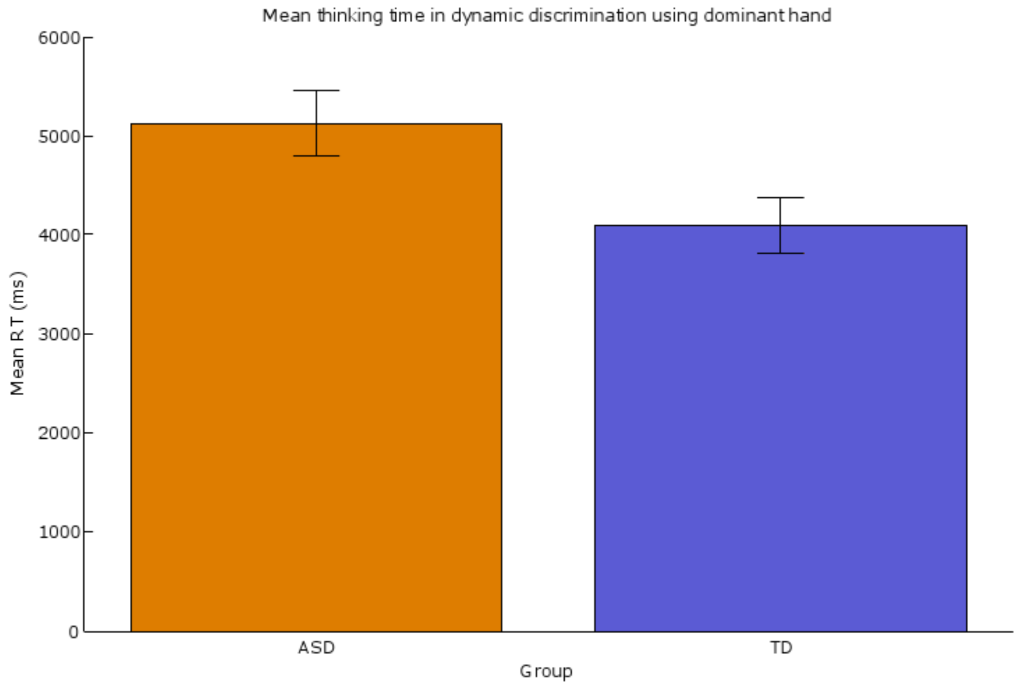

Figure 21: Dynamic discrimination 'thinking time' for both groups

initial speed. In dynamic change detection, the point of acceleration had a significant effect on RT, with earlier acceleration resulting in faster RTs. An earlier acceleration point is analogous to a larger target size at the end of the trial, as relatively more time has elapsed in which the target is expanding at a faster rate. This effect was not found in dynamic discrimination. The rate of acceleration, however, (and consequently the larger end-size of the target) significantly affected RT in dynamic discrimination when subjects used the dominant hand. The faster acceleration rate resulted in faster RTs for both groups.

Effects of variables within the videos used in dynamic conditions should perhaps be viewed tentatively as an analysis of RT depending on e.g. the value of u is not independent of the combination of the other variables u is presented alongside. For this reason further discussion of dynamic conditions will consider the task as a whole as opposed to discussing each manipulated variable.

Group by variable effects

While the psychophysical variables detailed above had a similar effect for both groups, fixation duration (from the centre detection task) had a differential effect on the two groups. Although there was no significant fixation duration*group interaction effect, parameter estimates showed that RTs to central targets after the shortest interval were equivalent for the two groups, while the two longer intervals resulted in significantly longer RTs for the ASD group compared to the control group.

Group effects

When a static target was presented centrally, the two groups produced significantly different mean *RT*s with both hands, with the TD group responding quicker than the ASD group. The group means also differed significantly when the target was presented at the side when responding with the nondominant hand, again with the TD group responding more quickly than the ASD group. The two groups responded equivalently using the dominant hand when responding to the lateral stimulus.

The ASD group's mean *RT* was not affected by target location when performing basic detection tasks, although the TD group produced significantly different *RT*s for the two detection tasks when using the nondominant hand, with faster responses to a centrally located target.

The ASD group did not show any deficit in static discrimination, performing at a level comparable with the control group.

The ASD group did show a selective deficit in discrimination when the stimuli were dynamic and this was found to be independent of both IQ and visuomotor delay (as recorded in the centre detection condition). This finding was only true for the dominant hand.

Hand effects

There was a consistent hand effect for both groups throughout the game. In conditions where there was a significant effect of hand (centre detection, static discrimination and dynamic discrimination), the nondominant hand was significantly faster than the dominant hand.

Discussion

The present study was designed in order to assess visual detection and visual discrimination of static and dynamic stimuli in ASD and neurotypical children. It was also designed to address a need for studies using common methodologies in a variety of perceptual tasks, in order to make more clear generalisations about strengths and weaknesses in visual perception in ASD.

A novel computer game delivered five different tasks and within each, three common main effects were investigated: the effect of developmental group on RT; the effect of IQ on RT and the effect of hand used on RT. For each of the three static conditions one task-specific variable was considered, including duration between presentation of target (centre), size of target (side) and target comparison pair (static discrimination). In the dynamic conditions, the three variables manipulated in each video were also considered.

Results from the analysis of these task-specific variables highlighted sensitivity to known psychophysical variables such as relative size differences and Stimulus Onset Asynchrony (SOA).

There were a number of key findings from the analysis of the data. These findings will now be discussed with reference to previous studies and previously discussed theories. First, cross-condition comparisons will be summarised, followed by a discussion of each condition in turn.

Discussion of condition comparisons

Analysis highlighted a general hierarchy of task difficulty (with respect to RTs) within the game. Trends of relative RTs across the five levels in the game generally followed the same pattern for both groups.

Single-target location (central or lateral) did not affect RTs for the ASD group. Using (only) the nondominant hand, the TD group was significantly slower to detect lateral targets than central targets. This highlights that the preference for peripheral processing reported in ASD (Hirstein et al, 2001), is not coupled with more efficient peripheral visual processing. The significant difference between RTs for the two locations for the TD group using only the nondominant hand suggests differentiating roles and mechanisms of the two hands, which will be discussed at a later point.

As was expected, static discrimination took longer than detection of the single targets in one of the two locations. This was true for both groups. This finding was expected as any discrimination task is more cognitively demanding than a simple detection, which has a comparatively lower processing demand.

The same pattern (slower responding in two-stimuli conditions) was true for the single dynamic target versus a pair of dynamic targets. Again, this was the case for both groups. This difference is attributed to the need in the discrimination task to switch attention often and remain vigilant of multiple stimuli for a long period. This demand on divided attention resulted in longer *RT*s compared to the single dynamic condition.

Condition-by-condition discussion

Static detection

Superior visual detection in ASD was not found in the present study, counter to previous findings in other 'detection' tasks. The detection tasks have however provided support for differences in peripheral and focal processing in neurotypical children, and illuminated further the nature of the peripheral bias often found in ASD children. This will now be discussed alongside possible reasons for relatively poor target detection in the present task in contrast to previous findings of exceptional ability.

Why was there no superior target detection in the ASD group?

While the apparent deficit in simple target detection is counter to the common finding of faster target detection in ASD, it is important to note the circumstances in which superior target detection is claimed, compared to the target detection tasks included in the Tiger Spotting Game.

It may be that previous findings of superior target detection in ASD relative to TD was not replicated here as the tasks at which ASD subjects excel seem to exclusively be target detection *among distracters*, or tasks like EFT. There is a clear difference between previous 'target detection' tasks (more akin to visual search tasks) and those included in the game. In the present study the target is the only stimulus in the array or scene. The jungle background serves as a background for the fixation cross and the target and does not disappear or blink as the target appears, so it is held as a constant. Due to its constancy throughout the trial, it can be excluded as a part of the array or scene. In array detection tasks and EFT, the whole scene is presented after a blank initial screen, so the background and array (flankers and targets) are all *new* elements to be processed. As the jungle background is not a new element when the tiger is presented, it would seem that the task is fundamentally different. It would appear to have a much lower cognitive load: it does not require any filtering or inhibiting of other new objects, which is where the ASD individual's local processing bias becomes so advantageous. It is suspected that this is the reason for a lack of superior performance by the ASD group in this case compared to detection tasks discussed previously.

The detection tasks in the present study appear to provide one of two things: a visuomotor baseline RT, as was originally intended, or alternatively a task probing possible deficits in sustained attention.

Firstly let's consider the task as a predominantly visuomotor task, alongside previous 'detection' tasks. The task provides a visuomotor reaction time as opposed to detection time, as it is defined in previous detection tasks. While it is true that pressing the button is in response to detecting the change in the scene from jungle to jungle plus tiger, this is clearly a different kind of task. There is no real search element, with the tiger always appearing in the same location in the absence of flankers or distracters. Assuming that this task has assessed visuomotor responding, we can conclude that ASD children are slower to respond manually to visual stimuli than age-matched controls, at least when the target is located centrally. There appears to be little literature detailing visuomotor reaction times in ASD children however reports of clumsiness in Asperger Syndrome (Asperger, 1944; Klin, 2006) suggest that motor slowness could be expected.

Now let's consider the task as one of sustained attention. The slower RTs in the ASD group could be an expression of a sustained attention deficit, coupled with comparable visuomotor responses for each group. (Comparable visuomotor responses have been shown by Meilleur, 2010, although this study used a wide range of participants, aged 14-37, and it is one of very few empirical studies on visually triggered RTs in ASD individuals). If we assume comparable motor responses, a problem with sustained attention could explain the difference in mean RTs between the two groups in trials with longer intervals between tiger presentations. Although ASD individuals often show tunnel vision and problems with attentional disengagement (highlighted in the ODR task described previously), with no target to focus on between target presentations, it might be the case that attention has been drawn to a more salient region of the background.

As tasks like EFT lead to a pop-out effect in ASD participants, meaning that attention is immediately drawn away from its original point toward the target, it would initially seem possible to rule out wandering attention in this case, as the pop-out would immediately direct the attention to the target. If the task had involved a search element this would be true, as EFT has shown that TD children do not experience this pop-out effect in search tasks. However, as the task involves no search, this explanation is not valid. As it is being presumed that the TD children have no problems with sustained attention, their attention should always be on the fixation point, where the tiger will appear. So if the ASD child's attention wanders into the background while the TD child remains at the fixation point, *even* with a pop-out effect for the ASD child to return to the target, this would still not offset the TD child's time: with attention in the correct location, it seems logical that their time would be faster.

It would have been useful to include trials with a white background in place of the jungle background to serve as a comparison, as was originally intended, however restrictions within E-Prime meant that this was not possible due to restricted memory capacity. Trials with a white background would have served as a useful comparison as the background would not have provided the salient regions that are perhaps drawing attention into the jungle background at the expense of maintaining attention on the fixation point.

What do the detection tasks tell us about peripheral and focal vision?

Using the dominant (and presumably more controlled) hand, ASD children were slower than TD children to detect central targets, although comparable when detecting lateral targets. Initially, these findings could be seen to suggest that the deficit in central target detection in ASD might have been due to the location of the target, and the inherent need to use focal vision. Focal vision is reportedly avoided by some ASD individuals (Hirstein et al, 2001) although as yet, the quality of their focal processing relative to peripheral is unclear. Although the ASD group did not show superior detection in this task, they show no deficit, in line perhaps with this predominant use of peripheral versus focal vision.

While it is clear that findings from the detection tasks do not replicate previous findings of superior target detection in autism relative to TD children, they do highlight a definite difference in ability in the ASD group relative to the TD group with respect to peripheral versus focal vision. However it does not appear to provide evidence of significantly more efficient peripheral versus focal vision in ASD, as might have been expected by the reported bias (ibid). In fact, it was not the ASD group, but the TD group, whose mean RTs for the centre and side detection tasks differed significantly. This suggests that the normally developing child's preference for focal processing may go hand-in-hand with their peripheral vision being significantly less effective than their focal vision. As target location made no *significant* difference to the ASD group's mean RT, this suggests that while peripheral processing may be their habitual mode of processing, it is not significantly more accurate than their focal vision. This supports evidence that an ASD child's predominant use of peripheral vision could merely be to alleviate symptoms of sensory overload (Bogdashina, 2003) rather than because it has superior processing abilities compared to their focal vision.

Static discrimination

No deficit, nor enhanced ability in static discrimination for ASD children

There appears to have been no specific deficit in static discrimination in the ASD group. This supports, to an extent, findings by Plaisted et al (1998), Kemner et al (2008) and Kovattana and Kraemer (1974). These studies found enhanced abilities in discrimination of highly similar stimuli and enhanced discrimination of target relative to flanker in a search task, and comparable performance to TD on a size discrimination task respectively. It does however go against O'Riordan and Plaisted (2001)'s suggestion that perceptual differences are amplified in ASD. While the ASD children in this study appear not to have any enhanced discrimination ability (as it is defined in the present study), their comparable performance is further evidence that perceptual discrimination abilities appear to at *least* develop normally in autism.

As Kemner et al (2008) found that PDD subjects were *significantly faster* than TD in a target detection task (often described as a test of discrimination ability), it would be interesting to understand why there was found to be no superior discrimination abilities in this instance, although clearly no deficit relative to typically developing children. Eye-tracking in further study would perhaps illuminate the cause of this finding. Using eye-tracking techniques, Kemner et al reported that fixation durations for the PDD and control group were of equal length, although the clinical group needed fewer fixations in order to make an accurate discrimination. If fixations for the two groups were of equal length in the discrimination condition in the present study, and future studies using this game paradigm, then why was the ASD group not outperforming the TD group as they were in Kemner et al's study? If fixation duration is equal, then that would indicate that an equal number of fixations was also necessary for the two groups to perform comparably. This would be contrary to Kemner et al's finding of equal fixation duration coupled with fewer fixations by the PDD group. It may be due to the location of the targets in the present study: targets were located on the periphery, at least 14.4cm apart. This is a much greater distance than in Kemner et al's study, which used an array of slanted lines and a horizontal line, which were packed closely together. Due to the relative location of the two targets in the present study it is likely that saccadic movements were necessary in the present study, while it was reported that saccades were not made by a number of ASD subjects in the Kemner et al study. This would suggest that ASD individuals do not have an advantage in discrimination (or target detection) when the two stimuli are far enough apart to require more than a glance to gather the information needed to make a perceptual judgement.

With reference to executive dysfunction and difficulties with attention switching it might be the case that ASD children in the present study made fixations for a longer period, but made fewer fixations: this would be the reverse of the fixation duration finding in Kemner et al's study, although would still be in-line with their suggestion that ASD subjects are better able to appraise discrimination targets with less information (reflected in shorter reaction times in their study). Longer fixations would also be in-line with attention shifting deficits found in ODR.

It is important to note however that very little work has been carried out on size discrimination in ASD, so it may be that size discrimination makes different cognitive and executive demands than previous tasks showing enhancements, such as novel pattern discrimination (Plaisted et al, 1998). As the jungle background was asymmetrical there was no way in which to compare the tigers using reference points in the background, perhaps making the task less suited to ASD children's enhanced discrimination abilities. It can be assumed that differences may be more apparent when the background is constant for each stimulus. With no background of similarity, as there was in Plaisted et al's discrimination task, ASD participants are assumed to be less able to ignore the irrelevant background in the current task. This in turn results in them performing at the level of TD children, as opposed to exhibiting superior discrimination abilities as is often the case.

Detecting change in a single dynamic stimulus

Dynamic change detection of a single lateral stimulus appeared to be equally difficult for both groups in terms of RT, however, the ASD group gave significantly more incorrect answers for the first and only time throughout the game. When ASD subjects gave a valid answer, that is, after the acceleration and before the end of the movement, their RTs were comparable to those of TDs. The lower accuracy rate does indicate however that the ASD group were much more prone to either stopping the tiger before there had been a change in speed or missing the change in speed entirely and pressing the button once the tiger had stopped moving. As there was an effect of IQ in this condition (when analysing correct responses), it seems possible that the higher incidence of pre-emptive or time-out situations in the ASD group was due to difficulties in understanding this comparatively difficult task instruction. In order to instruct subjects as clearly as possible in this task, the verbal instruction from the game's narrator was quite lengthy and it is possible that the ASD children did not understand the instruction as well as the TD children and only succeeded to give RTs equal to those of TD participants after trial and error (explaining the higher inaccuracy rate). From watching participants on this task it seemed that if ASD children failed to notice the change in acceleration they often let the trial run to the end before pressing the button. Conversely, TD children seemed to know that they had missed the change in acceleration and pressed the button before the trial ended so as to have recorded a time. This seems likely to largely be a problem with generally lower IQ, perhaps coupled with difficulties in sustained attention (Corbett et al, 2009).

Dynamic discrimination deficit in ASD: an expression of an executive dysfunction?

The key group effect in the present study is the striking deficit in dynamic discrimination, especially when considered against ASD's intact discrimination abilities with static versions of the same stimuli. It should be noted that this finding remains true even when the relatively longer visuomotor delay (if we are to refer to the detection tasks as visuomotor tasks) and relatively lower IQ of the ASD participants was considered. The sudden drop in ability when the discrimination becomes an ongoing one suggests that there may be a problem with attention switching in the ASD group compared to the TD group, as reported in the ODR task. It is clear that there are few cases, if any, where there have been response suppression errors in the ASD group, as this would be shown as a speed-accuracy trade off. While the anti-saccade task found an inability to inhibit responses, this was not found in this case, possibly due to the explicit game nature of the task: participants understood that incorrect answers would result in a penalty. Instead, ASD children were significantly slower, most likely due to ineffective switching of attention to- and -from each tiger. As

*RT*s for dynamic change detection (Task 4) are comparable for the two groups it is clear that the reason for longer *RT*s in the discrimination is not merely a manifestation of slower processing of acceleration. It would appear that when constant monitoring is not necessary in order to make an accurate discrimination, ASD children are able to do so as quickly as TD children, although constant monitoring of two stimuli (probably located too far apart to be processed in the absence of saccades) proves problematic. It is anticipated that eye-tracking would uncover a tendency for ASD subjects to become 'stuck' on one stimulus and therefore require longer before they notice a difference. This sort if finding would sit alongside ODR findings of slower *RT*s after invalid cues: once attention has been drawn to one location it is more difficult for ASD children to move that attention elsewhere.

However, if Kemner et al (2008)'s finding of fixations of equal duration between groups is true for dynamic stimuli, then it may be that ASD particpants are having difficulty holding the size of each tiger in visuospatial working memory as they switch to the other (Minshew et al, 1999). Eye-tracking is therefore vital in order to illuminate the reason for this slower response time in ongoing dynamic discrimination.

One game, five tasks, one common explanation

Although in some cases a number of possible causes have been postulated, attentional aspects of executive functioning seem to be a common factor in each instance. In previous studies, it is most often the case that it is possible to explain findings in terms of atypical executive functioning, although this appears only to be the prominent explanation in higher-level perceptual tasks such as ODR. Lower-level tasks such as EFT seem to be associated with references to processing styles such as the WCC account. The finding of probable executive problems throughout the Tiger Spotting Game seems to suggest that executive dysfunction may be the most appropriate way in which to consider perceptual anomalies that have been empirically tested to date, instead of segregating lower- and higher-level processing into WCC-based explanations and executive dysfunction theories.

The Tiger Spotting Game as a psychophysical methodology

The all-encompassing method of delivering a tiered range of tasks introduced in this study has meant that comparisons can be drawn in a meaningful way, not available to us if we were to assess similar tasks within the literature. By including the same stimuli and background in every tasks, with the same response method, the same style of instructions and the same participants, it has been possible to investigate how the same two groups of children perform in a variety of tasks, and inferences have been made with reference to their performance on readily comparable tasks within the same game. As well as uncovering what could be a consistent role of executive function in ASD performance, the game format has also uncovered a consistent hand effect, highlighting a very unusual role of hand across a variety of different stimulus-response scenarios.

Hand used: an unexpected effect

There was initially no hypothesis regarding the effect of hand used on *RT*s: it was certainly not anticipated that anything unusual would be evidenced. It has usually been found that the dominant hand makes faster responses to visual stimuli than the nondominant hand (e.g. Rabbitt, 1978). In this case however, there seemed at times to be huge discrepancies between the two hands, in the opposite direction to that found in many previous psychophysical studies.

Common sense and previous experience would suggest that the dominant hand should react more quickly to stimuli than the nondominant hand: it is used much more frequently than the nondominant hand and is the hand we tend to automatically use when given a free choice. (Mamolo et al, 2006 found that we use our dominant hand when an object is placed along our midline, equidistant from both hands, and that in some tasks we may also cross our preferred hand across the midline of our body to interact with a contralateral object.) This tendency highlights the extreme bias often seen toward the dominant hand. In the present task, on occasion, this determination to use the dominant hand, regardless of its contralateral positioning to the response button, was exhibited by some of the children. It should be noted however that the child was always reminded of the correct hand to use for both buttons and they were not allowed to complete the task using just the dominant hand. Ironically, a number of children said they did not want to use their nondominant hand as they felt they would not perform as well on the task using the non-preferred hand.

The current finding of a faster *non-dominant* hand is therefore intriguing. The hand effect was found in the simplest condition, a basic reaction time task, through to the most complex task. The pattern was unchanging throughout, and importantly, was true for both groups, highlighting that this was not a differentiating ASD trait or deficit. As the finding was also found in a number of the left-handed subjects this suggests that this is not due to the task being geared toward the right hemisphere. However, further investigations may benefit from assessing left-handers' ability with the nondominant right hand. As so many children play computer games and use computers regularly, it is possible that left-handed children become practised using their nondominant hand, especially in situations like those created in the Tiger Spotting Game.

As there were significantly fewer left-handed participants than there were right-handed, it was initially a concern that the left-handed subjects adhering to the unusual faster non-dominant pattern were chance cases. If this were the case this would suggest that perhaps the findings were an artifact of a lag for the right button on the SR-box. In order to ensure that the hand effect was in fact genuine the experimenter completed the first task using only the dominant hand (right). This meant that for the first half of the centre detection task the right hand responded with the right button and for the second half the same hand responded with the left button. As the same hand was used to press both buttons, any difference between the mean response times recorded by the two buttons would be due to press-record lag in the SR-box as opposed to differences in responding time. It is not thought that there should be any adverse affect of the experimenter completing this task as opposed to a naïve participant as it is a very primary motor response, which should be robust to experimenter knowledge biasing results.

A t-test comparing RTs recorded by both buttons (using the same hand) reported no significant difference. This suggests that the lag between pressing the button and the time being recorded was equal for both the right and left buttons. Slower RTs for the dominant hand was therefore not due to differences between the two buttons. The hand difference then is a true finding that warrants investigation in further study.

Why was the nondominant hand faster to respond than the dominant hand?

Having rejected the possibility of the hand effect being due to problems with the apparatus, a discussion of the relevant literature will now be given, in order to identify a possible cause for this unexpected finding.

Although the majority of psychophysical studies assessing difference in RTs for the two hands find a faster dominant hand, there appears to be a small number of studies reporting findings similar to those reported here. Using right-handed adult participants, Leocani et al (2000) uncovered a similar finding in a series of auditory forced choice tasks and suggested that the dominant hand is more inhibited than the nondominant hand. The dominant hand concentrates on giving the correct answer by producing deliberate movements, while the nondominant hand responds in a less restricted manner, as it lacks the concentration of resources offered to the dominant hand. An early suspicion during data cleaning for the present study was that perhaps the nondominant hand was somewhat disconnected and responded much more freely, with little engaging in the cognitive aspect of the task. This study seems to at least corroborate this suspicion. Annett and Annett (1979) also found a similar result in a small-scale study assessing RTs in a simple stimulus-response task (very similar to the centre detection task in the present study). Two strongly right-handed adults who were practised at the task were tested in the visual detection task and it was found that in both participants the nondominant left hand was faster to react to the simple stimulus than the dominant hand. This difference was significant in one of the two participants. Ortiz et al (1993) also found a faster nondominant hand, although in this case the task was one of auditory discrimination. As with the previous study, this only included right-handers so these findings may point more to the relationship between hemispheric specialisation and the specific requirements of the task than answers to questions of hand dominance.

Although there are a small number of examples, there is comparatively little evidence of this counterintuitive finding. The tasks used vary across different modalities and in the majority of cases only right-handed participants are tested, making it difficult to avoid assumptions of left hemisphere dominance for the specific tasks. A number of authors do not investigate hand effects, even when both hands were used. It could be that these authors have also uncovered this counterintuitive finding, although decided to discount it.

What is most promising about the current finding is that it was not found solely in the right-handed participants, suggesting that it is not merely demonstrating that the task is a predominantly right-hemisphere task. As left-handed subjects were a clear minority however (21% of the sample), it might be beneficial to include a larger proportion of left-handed participants in any subsequent experiments focusing on hand-dominance effects. As autistic children of the appropriate age are relatively few, and the number of left-handed individuals in the general population is far out-weighed by right-handers, it may be most appropriate to test TD children, where the potential sample population is larger.

Study limitations

Small limitations in the present study have already been discussed with reference to particular tasks. More general limitations will now be discussed.

Power problems

Low power was a recurring problem for analysis of data from the nondominant hand. As the number of data points is either equal or very close to being equal between the dominant and nondominant data sets, it is likely that this reduced power is due to increased variance in the nondominant hand. The only way to control for this would be to increase the number of participants used in further study so as the variance is diluted to an extent and the larger sample would itself increase observed power.

Analysis and associated problems of sample size

Where IQ as a covariate had a significant effect on RT, there were a small number of occasions in which a small fraction of the variables to be entered into further covariate analysis were not normally distributed. This meant that parametric tests, like the ANCOVA, were not the most appropriate statistical test. It would have been ideal to conduct equivalent nonparametric analysis, to ensure that this deviation from a normal distribution was factored into analysis, ensuring that results were as accurate as possible. However, there is no standard method for conducting nonparametric analysis with a covariate. As there was only ever a small fraction of variables not lying on a normal distribution, it was decided that parametric tests with a covariate would be performed. In future studies, it would be beneficial to rectify this problem, so as analysis is as rigorous as possible. This could be done either by increasing the sample population, so as to dilute variance and thereby increase the likelihood of a normal distribution, or, by performing a partial correlation of the ranked data with a covariate, as a means of addressing the normality problem while still incorporating a covariate. This method should be investigated further in order to ensure that it is a legitimate method to use for analysis of the data collected. Due to time restrictions, this was not possible for the present study, however the variables not normally distributed were always a clear minority, so it is likely that the parametric ANCOVA is sufficient in this case.

It should also be made clear that with a relatively small sample size (12 subjects per group), checks of normality are very sensitive to variance. For this reason it seems to be a valid assumption that the lack of nonparametric covariate analysis (probably only necessary due to the extreme sensitivity of normality checks) is not adversely affecting the results of the present study. The clear patterns in the data, particularly evident in Figure 20 shown in the previous section, also indicates that sample size and slight deviations from normality in a small number of cases are unlikely to be adversely affecting results.

ASD variability: its effect and possible causes

As previously discussed with reference to observed power, variability was often very high in the ASD group. Consistently, standard deviation for the ASD group was much higher than that for the TD group and this is the likely cause of the power problems detailed above. There are a number of possible explanations for this wider spread of RTs in the clinical group. All but one of the ASD children were in the IQ range of the TD group, and 9 of the 12 TD children were in the IQ range of the ASD group. For this reason it is unlikely that variability is due to IQ, as the majority of each group fell into the IQ range of the other.

Impulsivity, a known trait in some ASD individuals, could however be one reason why, as a group, they were a lot more variable than TDs. High intra-individual variability (IIV) has been found in ASD and ADHD and the two conditions are known to share some cognitive deficits such as inhibitory control (Geurts et al, 2008) and other clinical characteristics (Frazier et al, 2001). Checking for any comorbid conditions such as ADHD may have been beneficial, as it was noted that a number of the children were very quick to focus on the task, while others were unable to focus on the task without encouragement. Due to practical reasons in the present study, exact diagnosis was not stipulated in the participant criterion and the sample also included both children in mainstream education and a special school.

A second possible cause of this variability may just be due to the very nature of autistic disorders. As a spectrum disorder, it is obvious that any group of ASD individuals will carry different autistic traits from one another. Some children frequently sought encouragement and validation when responding, while others needed no such input. Variance may therefore arise when less confident children felt that they required more support and showed a degree of reluctance when responding.

If attentional atypicalities are being considered as the main deficit in the ASD group throughout the game then varying levels of attentional dysfunction within the group (perhaps largely determined by specific diagnosis) may also be contributing to the much wider distribution of mean RTs in the clinical group.

Directions for future research

As well as addressing limitations discussed above in future research, the findings of the present study have also highlighted some interesting directions for further study using the Tiger Spotting Game or a revised version of it. These new ideas and additions to the paradigm will now be discussed.

ASD and comorbid conditions

The findings of the present study have largely been explained as attentional deficits, inline with executive dysfunction theory. Previously referred to as a limitation, high levels of variability in the ASD group could also inform further study. If there were children in the ASD group with comorbid conditions (specifically ADHD), it would be of interest to compare that subset of children to the other ASD children, without any comorbid condition, to further probe the nature of this attentional deficit in dynamic discrimination and skill in static discrimination.

Testing lower-functioning children

Having produced results suggesting that this game-style methodology is fruitful, it now seems important to build upon this to address the problem of a current bias in the literature: very few studies (including this one) test lower-functioning children. Much study has focused on higher-functioning children and it is not clear whether the findings are truly representative of autism, or of a subset of the higher-end of the spectrum.

In order to be able to test children across the wider autistic spectrum it may be beneficial to consider altering the way in which participants respond to the stimuli. Cognitively mapping a button to an abstract concept may be difficult for lower-functioning children, especially if they are not familiar with conventional console games. A much more natural response may be for participants to touch the stimuli, so the use of a touch screen in place of a SR-box may allow for lower-functioning children to be tested more effectively. It is not anticipated that this would alter the handedness finding although it would be interesting to ascertain whether a more natural response perhaps reduces the reluctance of the dominant hand to commit to a response. The use of the button may be allowing the dominant hand to over-think its answer. If we time ourselves catching a falling object with both hands the dominant is generally faster and this may be due to the natural as opposed to more artificial responses relied upon in computer games.

Although the use of a more natural pointing response is appealing in theory, the issue of response mechanism is much less straightforward in practice. Having already tested a low-functioning non-verbal child (male, 12 years old) on the game as it currently stands, it is clear that motor response in-fact may not always be the most reliable measure. This particular child was reluctant to initiate a response, even though he had identified the larger of the two tigers. He would often point to the screen and then seek reassurance from someone before he committed himself to an answer. Having watched the same participant on a touch screen language intervention game (McGonigle-Chalmers, 2008), it is clear that initiation problems in this particular child are not resolved by the use of a touch screen in place of a SR-box or a mouse (in the case of the Eventaurs game mentioned above). It is clear that for this child, the use of a touch screen would not be beneficial. (Perhaps a motion-sensitive device, such as the controller used for the Nintendo Wii console, would be appropriate in this case?). Due to the extreme variability of ability and experience in ASD children, it is not possible to say that other children would not benefit more from a touch screen, or indeed any other possible response device.

If it is the case that response-reluctance is a recurring feature in lower-functioning ASD, then any method requiring a visuomotor action will be insufficient on its own. For this reason, employing two techniques for data collection simultaneously may be the most appropriate method for data collection in future studies. A visuomotor response and an eye-tracker could be used simultaneously to give the opportunity to gather more data on both cognitive reaction times (shown in the eye tracking data) and visuomotor times (shown in the visuomotor data). A number of different visuomotor responses will be tested in pilot studies to identify a method that is suitable for the majority of subjects, and is practical to use alongside an eye-tracker. Of course, with such heterogeneity among ASD children, no one method is likely to suit all, especially if lower-functioning children are to play the same game as higher-functioning children. The question of changing the visuomotor response to suit the participant is likely to be contentious, as clear comparisons cannot be drawn between subjects when different responses have been used, unless it can be proved that each child is equally good with all response devices.

As well as response device, there are other ways in which the game can be altered to accommodate lower-functioning children. It might be possible to change the instructions for lower-functioning children. This would have to be done very carefully, as instruction itself can alter *RT*s (Borghi and Scorolli, 2009), so the phrasing of the instructions would have to match in terms of their semantic content etc.

Programming a threshold seeking algorithm into the game would also perhaps make it accessible to children of varying ability, as the game would be able to deliver trials at a suitable level, depending on the child's ongoing performance. This way the game would still be using the same parameters, but data would only be collected at levels suitable to each child. This would still enable us to see trends among subjects, identifying tasks that they find relatively more difficult, without distorting these patterns by requiring lower-functioning children to complete the tasks at a level that is too advanced for them or completing slightly altered tasks.

If these suggestions could be implemented successfully then it would be possible to pinpoint areas of difficulty in visual processing, from simple visuomotor detection through to stimulus-driven cognitive decisions, across the whole spectrum of autism spectrum disorders. This in turn would provide a starting point for further understanding the core sensory and perceptual deficits in ASD.

Eye Tracking

When investigating visual processing it is obviously advantageous to verify what a subject reports seeing using an eye tracker. When used in conjunction with psychophysical measures as suggested above it should prove very fruitful.

Karatekin (2007) has written a comprehensive review of the current literature on eye tracking studies with children and adolescents published since 1988. For more details on eye tracking procedures and methodology along with a more detailed account of previous findings see this near-exhaustive literature review.

Eye tracking will undoubtedly be important in explaining the significant slowness of ASD participants in the absence of lower accuracy rates. As it will be an important addition to any further study, a brief overview of basic eye tracking techniques will be detailed, followed by a discussion of its potential use in further studies.

What kind of data can be obtained using an eye tracker?

There are a number of different kinds of data that can be gathered using eye-tracking techniques. A brief explanation of the two main types of eye movements recorded in eye-tracking studies will now be given.

Saccades

A saccade is a ballistic movement of the eye, used to bring a target into foveal vision. (Karatekin, 2007). They usually occur when we shift our attention toward an object to focus on it.

Fixations

Fixations are what follow a saccade. A saccade moves your eye and then you fixate on the area the saccade has moved you to. Using eye-trackers we are able to identify both the areas fixated in a scene, and also fixation duration. A fixation map allows us to essentially see the scene as the participant did. Yarbus's (1967) study is an ideal example of how fixation and saccade maps allow us to see from the perspective of the subject.

Implementing eye-tracking in The Tiger Spotting Game and further studies

Recording responses

As suggested previously with reference to testing lower-functioning children, eye-tracking could be employed as a secondary means of recording responses. This technique has already been successfully implemented in a number of instances (Stampe and Reingold, 1995). The eye tracker would be set up to record a response after a steady fixation on one target has been made for a minimum amount of time. This would give an indication of when a cognitive decision had been made, allowing us to view the visuomotor response as a motor response rather than assuming it to also be a cognitive response time. Using both eye-tracking and motor responding would allow for both responses to be acknowledged, while not relying exclusively on the motor responses that would likely tell us more about motor inhibition and initiation difficulties than perceptual processing.

Visualising shifts of attention

Having found that ASD subjects responded significantly slower than TD subjects to two simultaneously moving targets, it is now important to understand why. General lower intelligence has already been ruled out, as has a visuomotor delay. Although the ASD children did show a significant lag behind the TD children in the simple detection task, suggesting a visuomotor delay, when this was factored in, there was still a significant difference between the two groups' mean RTs. It has been suggested that in discrimination tasks like these, ASD participants exit the task too quickly on error trials, highlighting a restriction in the attentional capacity to gather all information pertinent to making a response. This would be an expression of visuo-spatial executive problems described by McGonigle-Chalmers et al (2008) as 'prospective working memory'. This however should result in lower accuracy rates as found by those authors when task complexity increased, which is not the case here: the difference is only in mean RT. The ASD participants are not exiting the task too quickly, as evidenced by their significantly longer RTs and comparable error rates. There would seem then to be two obvious reasons why this difference exists: ASD children do not notice changes as quickly as TD children, or they are not able to make the judgement as quickly as they are not effectively monitoring the constantly changing stimuli. The former suggestion does not seem to sit well alongside the comparable group RTs for single dynamic change detection in the present study (suggesting that the problem is not caused by a reduced ability to process looming motion). Neither does it sit well with O'Riordan and Plaisted (2001)'s assumption that perceptual differences are amplified in ASD. The latter suggestion of ineffective monitoring of the stimuli could easily be investigated using eye-tracking. By employing eye-tracking techniques it would be possible, in a sense, to experience the game as the ASD children did. By mapping out their fixations and also the duration of those fixations, it would be possible to confirm the suspicion that they are not effectively monitoring the stimuli (switching attention frequently enough).

It would also be possible to utilise eye-tracking techniques to *elicit* attention shifting. A gaze contingent design, in which a tiger is only presented when participants fixate it, would force participants to switch attention. The tiger not currently fixated would keep moving, although would be invisible to the observer until attention was disengaged from one target and re-engaged on the second. The target from which attention had just been moved would then become invisible, although would keep moving smoothly. If ASD participants were worse in this kind of condition compared to the current dynamic discrimination condition this would suggest that they are relying on peripheral vision to alert them to any changes in one tiger while they fixate on the other.

Sustained attention

As discussed previously, the significantly slower *RT*s for the ASD group in the basic detection task could be explained as stemming from a problem of sustained attention. Eye-tracking could be used in further studies to either verify or rule out this possibility. Simply monitoring fixations and saccades will allow us to identify differences between the two groups when they are required to remain fixated on a single location. When waiting for the target to appear, ASD subjects may be drawn to salient regions of the background and choose to fixate these as opposed to the fixation point. If eye-tracking does show sustained attention to be problematic in ASD, it is anticipated that it will show a narrowing of attention onto salient background features (perhaps areas of high contrast), as opposed to a large number of saccades and fixations suggestive of an idle scanning of the scene. The former would be expected due to the known disengagement problems and tunnel vision found in ASD. A bias toward local processing, already a well established finding, also suggests that lapses in sustained attention would not lead to 'wandering' attention, but to narrowing attention on small areas of the scene. As has already been suggested, presenting the tiger on a white background as means of a comparison would also be of interest in the sustained attention question if it were found that attention is drawn from the centre of the screen when there are no salient local stimuli to be drawn to.

Conclusion

It would appear from the present study that the locus of commonly found patterns of ASD performance in visual perceptual tasks is in attentional control. The executive dysfunction theories (relevant to attentional control) cited seem to be the most appropriate theory to explain the pattern of intact and deficient performance by ASD participants in the Tiger Spotting Game. Anomalies of executive functioning have been located at the level of visual perception and future research using this paradigm will further probe the nature of this executive deficit of attention at the level of eye movements and other fundamental visual processes.

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Appendix A: Matlab scripts used to create videos used in dynamic conditions

The Matlab script used to create the dynamic discrimination videos. % within the script signals that text following it is a comment and is ignored by Matlab when the script is run.

```
function DanandStan
clear all
close all
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%load in jungle
jungle=imread('jungle_background.jpg');
[X Y Z] = size(jungle);
```

This gives the size of the jungle scene in pixels: this was important in the initial designing of the experiment, as stretching the videos too much in E-Prime resulted in a noticeable decrease in the video quality. By changing the size of the jungle background and running the resulting video in E-Prime, it was possible to determine how small the video could be made without compromising too much on quality.

```
% load in tiger!!!!!!!
tiger = imread('tiger_off_white_beard22.jpg');

tiger = imresize(tiger, 1.2);
```

After trial and error, it was found that with some values of a (0.005 or higher), the tiger became too big for the background. With $a = 0.004$, the relative difference between the two tigers was too small, so the initial tiger was scaled up slightly to give the same effect, but to a lesser extent, which kept both tigers within the image boundary.

```
%time in seconds for animation
time = 9;
% starting speed (u) in units per frame, and acceleration

{for a1 = [-0.002 -0.003 -0.004]
    for u1= [-0.4]
        for  u2= [-0.4]
            for accstart = [0.4]}
```

This loop tells Matlab to run the script until it has created a video of each of the permutations of a, u and *accstart* (so, a_1=-0.002, u_1=-0.4, *accstart*=0.4: a_1=-0.003, u_1=-0.4...)

```
a2=-0;
                % tiger 1 coordinates
```

Tiger 1 is Dan (the faster tiger)

```
x1 = round(0.5*X-0.5*Xtiger); y1 = round(0.75*Y-0.5*Ytiger);
```

This Places Dan on the right (half way between the horizontal midpoint and the right edge).

```
% tiger 2 coordinates
                x2 = round(0.5*X-0.5*Xtiger);...
                 y2 = round(0.25*Y-0.5*Ytiger);
```

This places Stan (who does not accelerate) on the left (half way between the horizontal midpoint and the left edge).

Once the videos in the above loop were created, y1 and y2 were swapped, and the script was run again, in order to create the same videos with Dan on the left.

```
                % accstart
                % if accstart = 0 .5
                % then the tiger will start accelerating
                 1/2 way through a trial (so after
                % 180 frames if it's 360 frames long)
                %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
                % tell Matlab how close the tiger should be
                 at end of trial
                intial_distance = 190;
                % framerate =frames per second
                frame_rate = 24;
                %make list of frame numbers
                number_of_frames = frame_rate*time;
                start_acc_at_this_frame = round...
                (number_of_frames.*accstart);
                frames = [1:number_of_frames]-1;

                %  Work out scaling factors for tiger 1 and 2
```

Scaling factors for Dan (the tiger that accelerates at *accstart* point)

```
scaling_factors1 = makeScalingFactors...
(start_acc_at_this_frame,number_of_frames,...
                    u1, intial_distance, a1);
```

Scaling factors for Stan (the tiger that maintains initial speed throughout)

```
scaling_factors2 = makeScalingFactors...
(start_acc_at_this_frame,number_of_frames,...
                   u2, intial_distance, a2);
% create avi object with 24 frames per second
```

This is the instruction for naming the file according to the parameter values and how to compress it etc.

```
filename = ['juRTiger_a=' num2str(a1)...
'_accstart=' num2str(accstart) ...
    '_u1=' num2str(u1)...
     '_u2=' num2str(u2) '_Trial.avi'];
aviobj = avifile(filename,...
 'fps', 24, 'compression', 'cinepak',...
  'quality', 100);
```

These are instructions for naming the individual frames and saving them as JPGs.

```
for frame = 1:number_of_frames
```

The above simply means 'for all frames'.

```
filename = ['tiger_frame_' int2str(frame) '.png'];
                compositeimage = jungle;
```

This sets the jungle as the background on which the scaled tigers should be placed on for each frame.

```
 compositeimage = ScaleAndPasteATiger(compositeimage,...
                scaling_factors1, x1, y1);
```

Compositeimage is explained in 'function compositeimage' below.

```
 compositeimage = ScaleAndPasteATiger(compositeimage,...
                scaling_factors2, x2, y2);
                imwrite(padded_tiger, filename);
                imwrite(compositeimage, filename);
                %convert image into a frame
                f = im2frame(compositeimage);
                %add frame to movie!
                aviobj = addframe(aviobj,f);
            end
```

```
            % to save, look at AVIFILE
            aviobj = close(aviobj);
        end
    end
end
end

function compositeimage =
 ScaleAndPasteATiger(compositeimage,
  scaling_factors, xi, yi)
scaled_tiger = imresize(tiger,
 scaling_factors(frame), 'bilinear');
% pad tiger image with white border
```

(Scaled tigers placed on top of the old tiger. Scaled tigers have a border with the same dimensions as the original tiger picture's border).

```
pad = size(tiger)-size(scaled_tiger);
```

This ensures that the tiger is always superimposed in the right place, with the centre of the images always in the same place across frames.

```
padded_tiger = padarray(scaled_tiger, ceil(pad./2),255);
if size(padded_tiger,1)>size(tiger,1)
    padded_tiger(1,:,:)=[];
end
if size(padded_tiger,2)>size(tiger,2)
    padded_tiger(:,1,:)=[];
end
% this cuts out the white around ze kitty cat
idx = find((padded_tiger(:,:,1)<250).
*(padded_tiger(:,:,2)<250).*(padded_tiger(:,:,3)<250));
```

Every tiger picture has an off-white border. The instruction above finds all slightly off-white colour and makes it transparent, so the jungle replaces the white background. 255 is white, but it was difficult to make the tiger background all white, and 250 was found to be the best value: it removed all of the background white and did not pick up any of the off-white colour in the beard.

```
[x,y] = ind2sub(size(tiger),idx);
% paste tiger 1 into background at (xi, yi).
```

X1 and Y1 were specified above, after the *a*, *u* and *accstart* loop.

```
for t=1:size(x,1)
    compositeimage(x(t)+xi,y(t)+yi,:) = padded_tiger(x(t),y(t),:);
end
end
end

function scaling_factors =...
    makeScalingFactors(start_acc_at_this_frame,number_of_frames,...
    ui, intial_distance, ai)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
ScalingParameter = 7;
```

This value is arbitrary and was decided on through trial and error.

```
acceleratingframes = start_acc_at_this_frame:number_of_frames;
```

Accelerate from *accstart* point to final frame.

```
constantspeedframes = 1:(start_acc_at_this_frame-1);
```

Both maintain constant speed from start to the frame before accstart frame.

```
(constantspeedframes)=ui;
d(constantspeedframes) = intial_distance + ui.*constantspeedframes;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% assuming uniform acceleration
% from start_acc_at_this_frame to end of file
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
acceleratingframes = start_acc_at_this_frame:number_of_frames;
v(acceleratingframes) = ui+ai.*(acceleratingframes+1-
start_acc_at_this_frame);
d(acceleratingframes) = d(start_acc_at_this_frame-1)...
    +
    ui.*(acceleratingframes+1-start_acc_at_this_frame)...
    + 0.5*(ai.*(acceleratingframes+1-start_acc_at_this_frame).^2);
scaling_factors = intial_distance./d;
scaling_factors = scaling_factors/AlasdairsScalingParameter;
% plot stuff
```

The instruction below gives graphs showing speed/distance. These make it possible to check that one tiger plateaued while the other accelerated. Scaling fctor was also plotted, which was useful in the initial designing, as if the line ever went above 1 on the scaling factor axis the running of the script could be aborted before an error was given warning that the tiger was larger than the confines of the background dimensions.

```
figure
subplot(1,3,1)
plot(d);
title('distance-time graph')
subplot(1,3,2)
plot(v);
title('distance-speed graph')
% axis([0 360 0 max(v)]);
subplot(1,3,3)
plot(scaling_factors)
title('scaling factors');
end
```

Appendix B: Analysis of experiment proper using median as an expression of central tendency

Centre

Note, for the centre and side tasks there was no accuracy data as they were regarded as purely reaction time tasks.

Individual subject's medians for this component of the game were entered into a 2*3 repeated measures ANOVA. Within-subject factors were hand used (dominant/ nondominant) and fixation duration (500ms, 1000ms, 2000ms). Between-subjects factor was group (ASD/TD). Responses were partitioned by hand used to determine whether or not the data from the first and second half of the sub-game could be collapsed together and whether RTs from both the dominant and nondominant hand could be analsyed together in further tests. There was no main effect of group, suggesting that ASD subjects' motor response was equivalent to that of their TD counterparts and there was no significant motor delay. This suggests that any differences found in later sub-games are not due to a motor delay but due to sensory-perceptual and/or cognitive differences between the two groups. There was a significant difference between the longest and shortest fixation durations, with slower RTs for the longest fixation duration. As there was no main effect of group or a significant interaction between group and fixation duration there is no reason to suspect that the attention of the ASD children was wandering during the longer fixation duration to a greater extent than TD.

Side

RT data was entered into a 2*3 ANOVA and again there was found to be no main effect of group, with ASD and TD children performing equivalently. The visual field of the two groups encompasses the required space for later tasks.

Static discrimination

It was anticipated that IQ may have an effect on the more cognitively demanding tasks. For this reason the final three tasks were analysed with IQ as a covarirate. RT data was entered into a repeated measures ANCOVA and once again there was no effect of group.

Single dynamic change detection

An ANCOVA was run on $RT_{relative}$ data and there was found to be no significant difference between the two subject groups.

Dynamic discrimination

RT data was entered into a repeated measures ANCOVA. Tests of between-subjects effects found no effect of the covariate, and a trend towards a significant effect was found for group.

Observed power was $\approx$0.4. Due to the high variability within each group and this relatively low power it is probable that a greater sample size would have given a significant difference.

Appendix C: Pilot results

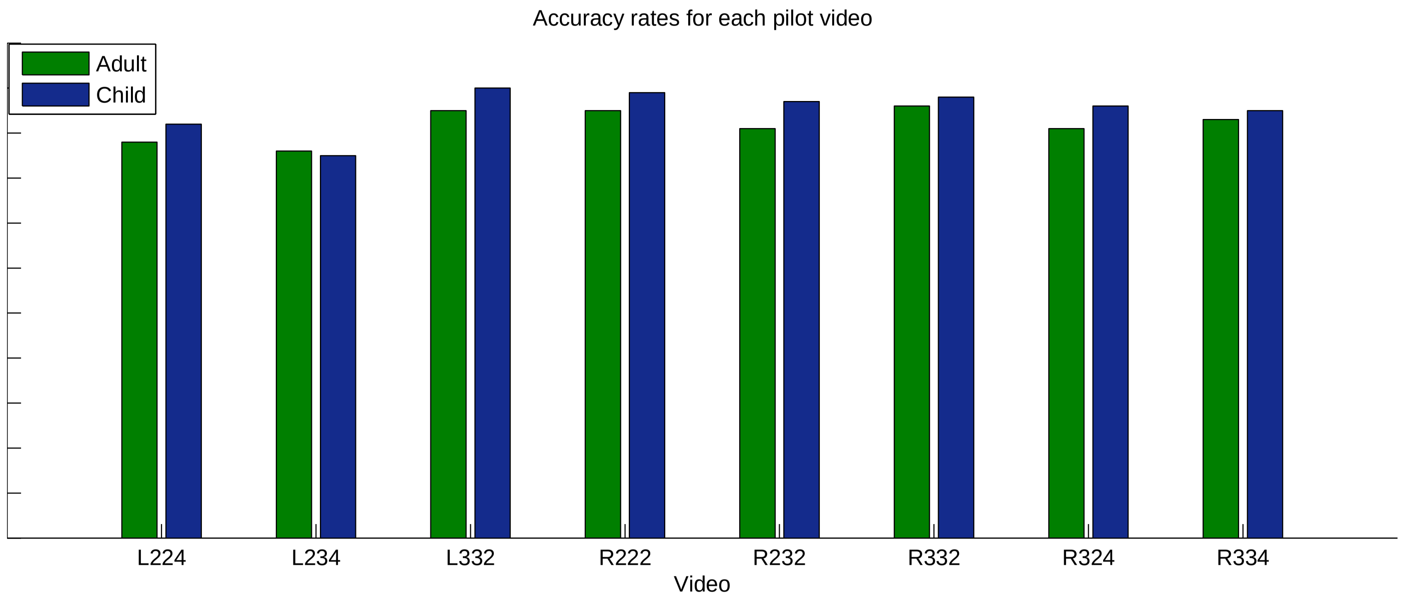

Figure 22: Accuracy rates for each video in the pilot experiment

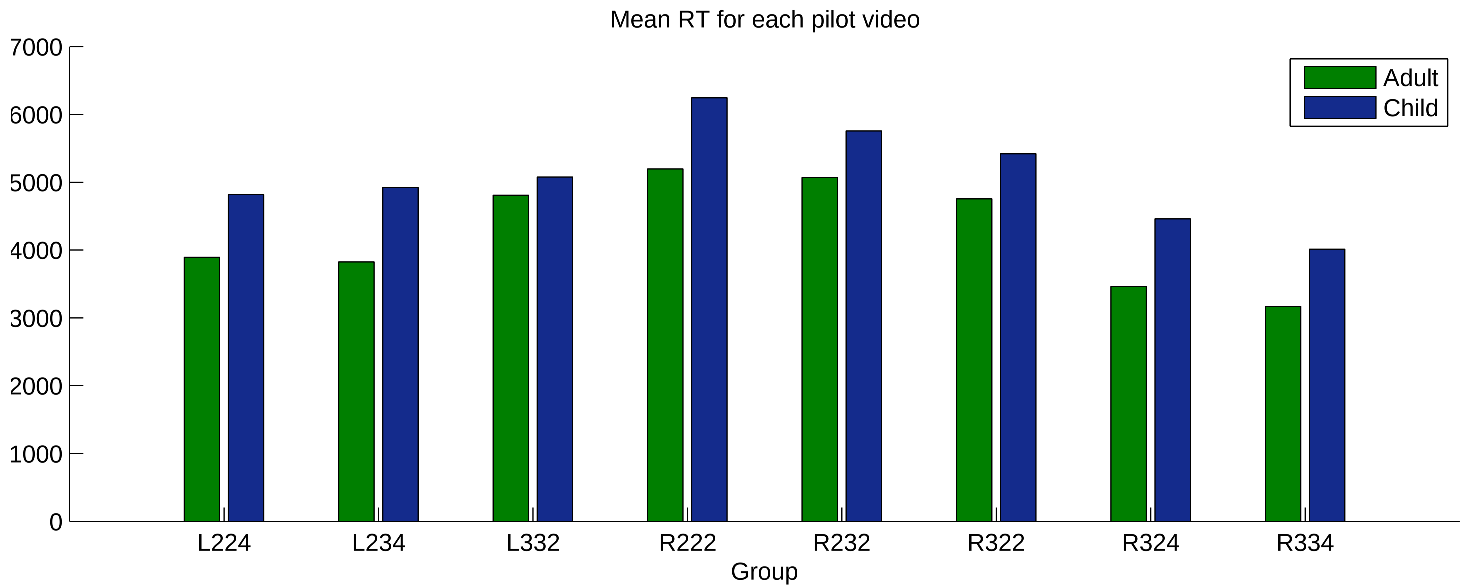

Figure 23: Mean RT for each video in the pilot experiment

Appendix D: Subject IQ standard scores and corresponding percentile ranks

Standard scores and percentile rank for the ASD group is shown in Table 43 and TD in Table 44. According to the K-ABC-II, a child would be of average IQ if their Standard score lay between 85-115.

Subject	Standard Score	Percentile rank
1	57	0.2
2	84	14
3	85	16
4	86	18
5	87	19
6	93	32
7	93	32
8	95	37
9	98	45
10	102	55
11	105	63
12	107	68

Table 43: IQ and percentile rank for the ASD group

Subject	Standard Score	Percentile rank
1	68	2
2	84	14
3	85	16
4	91	27
5	94	34
6	98	45
7	101	53
8	105	63
9	105	63
10	108	70
11	109	73
12	130	98

Table 44: IQ and percentile rank for the TD group